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MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

MCDONNELL DOUGLAS CORPORATION

SATURN S-IVB-509 STAGE ACCEPTANCE FIRING REPORT

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COORDINATED BY: J. H. LA PLANTE
PROJECT OFFICE - TEST
HUNTINGTON BEACH DEVELOPMENT ENGINEERING
SATURN/APOLLO & APOLLO APPLICATIONS PROGRAMS

PREPARED BY:
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY
WESTERN DIVISION
SATURN S-IVB TEST PLANNING
AND EVALUATION COMMITTEE

PREPARED FOR:
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
UNDER NASA CONTRACT NAS7-101

H B Mitchell for
APPROVED BY: A. P. O'NEAL
HUNTINGTON BEACH DEVELOPMENT ENGINEERING DIRECTOR
SATURN/APOLLO & APOLLO APPLICATIONS PROGRAMS

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY
WESTERN DIVISION
5301 Bolsa Avenue, Huntington Beach, California 92647 (714) 897-0311

ABSTRACT

This report presents an evaluation of the Saturn S-IVB-509 stage acceptance firing that was conducted at the Sacramento Test Center on 14 May 1969. Included in this report are stage and ground support equipment deviations associated with the acceptance firing configuration.

The acceptance firing test program was conducted under National Aeronautics and Space Administration Contract NAS7-101, and established the acceptance criteria for buyoff of the stage.

DESCRIPTORS

Saturn S-IVB-509 Stage

Saturn S-IVB-509 Stage Test Evaluation

J-2 Engine

Complex Beta

Countdown Operations

Saturn S-IVB-509 Stage Acceptance Firing

Saturn S-IVB-509 Stage Test Configuration

Sacramento Test Center

Sequence of Events

O_2-H_2

PREFACE

This report documents the evaluation of the Saturn S-IVB-509 stage acceptance firing as performed by MDAC-WD personnel at the Sacramento Test Center.

The report was prepared under National Aeronautics and Space Administration Contract NAS7-101 and is issued in accordance with line item 129 of the MSFC Data Requirements List 021, dated 15 September 1966.

This report evaluates stage test objectives, instrumentation, and configuration deviations of the stage, test facility, and ground support equipment.

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1. INTRODUCTION

1.1 General

This report was prepared at the McDonnell Douglas Astronautics Company - Western Division (MDAC-WD) Huntington Beach (HB), by the Saturn S-IVB Test Planning and Evaluation (TP&E) Committee for the National Aeronautics and Space Administration under Contract NAS7-101.

Activities connected with the Saturn S-IVB-509 stage included a pre-firing checkout and the acceptance firing. Checkout started at the subsystem level and progressed to completion with the integrated systems test and the simulated acceptance firing. The information contained in the following sections documents and evaluates all events and test results of the acceptance firing which was completed on 14 May 1969. The tests were performed at Complex Beta, Test Stand III, Sacramento Test Center (STC).

1.2 Background

The S-IVB-509 stage was assembled at MDAC-WD/HB. A checkout was performed in the vertical checkout laboratory (VCL) prior to shipping the stage to STC. The stage was delivered to STC on 31 March 1969 and installed on Test Stand III on 1 April 1969. The stage was ready for acceptance firing on 12 May 1969.

The APS modules were shipped to Santa Monica checkout laboratory for production acceptance tests. The modules were then shipped to STC for stage interface checks. No confidence firings of these modules were scheduled.

Table 1-1 lists the milestones of the Saturn S-IVB-509 stage events and dates of completion.

1.3 Objectives

All test objectives outlined in drawing No. 1B71775E, Test Plan Acceptance Firing, S-IVB/SV-STC, dated 27 January 1969 were successfully completed.

Stage acceptance objectives which provide maximum system performance evaluation were as follows:

a. Countdown control and operational capability verification

b. J-2 engine system performance verification

c. Oxidizer system performance verification

d. Fuel system performance verification

e. Pneumatic control system performance verification

f. Propellant utilization system performance verification

g. Stage data acquisition system performance verification

h. Stage electrical control and power system performance verification

i. Hydraulic system performance and J-2 engine gimbal control performance verification

j. Structural integrity verification

k. Auxiliary propulsion system stage interface compatibility verification

l. Ambient repressurization system performance verification

m. O_2-H_2 burner performance verification.

TABLE 1-1
MILESTONES, SATURN S-IVB-509 STAGE

Event	Completion Date
Tank assembly	3 Oct. 1967
Proof test leak and dye	10 Oct. 1967
Insulation and bonding	11 Dec. 1967
Stage checkout and join J-2 engine	16 Apr. 1968
Systems checkout	16 Sept. 1968
Ship to STC	31 Mar. 1969
Stage installed on test stand	1 Apr. 1969
Ready for acceptance firing	12 May 1969
Acceptance firing	14 May 1969
Abbreviated postfire checkout on stand	13 June 1969
Ready for storage	22 July 1969

2. SUMMARY

The S-IVB-509 stage was acceptance fired on 14 May 1969 at Complex Beta, Test Stand III, Sacramento Test Center. The countdown was designated as CD 614120. The mainstage firing durations was 452 sec; engine cutoff was initiated by the LH_2 depletion sensors.

2.1 Countdown Operations

Countdown 614120 was initiated on 13 May 1969 and proceeded to a successful acceptance firing on 14 May 1969. The acceptance firing was preceded by an O_2-H_2 burner firing, and an ambient repressurization test.

2.2 J-2 Engine System

The S-IVB-509 stage utilized an uprated (230,000 lbf thrust) J-2 engine, (S/N 2124). All systems operated satisfactorily and the performance predictions were well within the allowable deviations. All hardware functioned normally.

2.3 Oxidizer System

The oxidizer system functioned adequately supplying LOX to the engine pump inlet within the specified limits. The net positive suction pressure (NPSP) available to the LOX pump inlet exceeded the engine manufacturer's minimum requirement at all times.

2.4 Fuel System

The fuel system performed as designed and supplied LH_2 to the engine within the limits defined in the engine specification. The LH_2 tank pressurization system adequately controlled LH_2 tank ullage pressure throughout the firing and during the repressurization periods. Post-test inspection disclosed that the lower fuel duct vacuum annulus had lost its vacuum and the entrapped gases contained approximately 97 percent GH_2 and 3 percent He. The lower duct was removed and leak checked revealing a crack in the lower bellows of the lower duct. A failure analysis was completed and it was concluded that the bellows experienced a flow resonance (a high frequency low amplitude vibration) which causes fatigue failure.

Corrective action has been initiated which will fabricate and install flow liners in the low pressure ducts to eliminate any flow resonance in the bellows. This is to become effective on S-IVB-506N and subs.

2.5 Pneumatic Control and Purge System

The pneumatic control and purge system performed adequately during the acceptance firing. All components functioned normally.

2.6 Oxygen-Hydrogen Burner System

The O_2-H_2 burner performed satisfactorily during the 460 sec of operation. The LH_2 tank was repressurized 177.3 sec after burner start, and the LOX tank repressurization was terminated approximately 0.2 sec later.

2.7 Propellant Utilization System

The PU system generally performed satisfactorily. However, a minor anomaly occurred when the closed-loop valve response exhibited anomalous activity because of a sticky PU valve. The valve was replaced.

2.8 Data Acquisition System

The data acquisition system performed satisfactorily throughout the O_2-H_2 burner and mainstage firing. Two hundred and twenty-seven measurements were active of which two failed resulting in a measurement efficiency of 99.1 percent.

2.9 Electrical Power and Control Systems

The electrical power and control systems performed satisfactorily throughout the acceptance firing. All firing objectives were satisfied and all systems variables operated within design limits.

2.10 Hydraulic System

The hydraulic system operated properly supplying pressurized fluid to the servo-actuators. All specified test objectives were achieved and all system variables operated within design limits.

2.11 Flight Control System

The dynamic response of the hydraulic servo-thrust vector control system was measured while the J-2 engine was gimbaled during the acceptance firing. The performance of the pitch and yaw hydraulic servo control systems was satisfactory.

2.12 Structural Systems

Structural integrity of the stage was maintained for the vibration, temperature, and thrust load conditions of the acceptance firing with the exception of cracking and peeling of Korotherm ablative coating on certain areas of the forward skirt. The damaged coating is to be repaired under direction of Materials & Methods/Research and Engineering.

2.13 Thermoconditioning and Purge System

The thermoconditioning and purge system functioned properly supplying purge and environmental conditioning to the stage within design limits.

2.14 Effectiveness Engineering

All malfunctions of Flight Critical Items were investigated and documented as follows:

Total number of malfunctions	4
Number of items reworked in place	1
Number of items replaced	1
Number of items requiring final disposition	1

3. TEST CONFIGURATION

This section describes the stage and ground support equipment (GSE) deviations and modifications from the flight configuration affecting the acceptance firing. Additional details of specific system modifications are discussed in appropriate sections of this report. Details of the S-IVB-509 stage configurations are presented in drawing No. 1B66684, S-IVB/V Stage End-Item Test Plan.

Figure 3-1 is a schematic of the S-IVB-509 stage propulsion system and shows the telemetry instrumentation transducer locations from which the test data were obtained. The propulsion system orifice characteristics and pressure switch settings are presented in tables 3-1 and 3-2. J-2 engine S/N 2124 was installed.

The propulsion GSE consisted of pneumatic consoles "A" and "B," two propellant fill and replenishing control sleds, a vacuum system console, and a gas heat exchanger.

3.1 Configuration Deviations

Configuration deviations required for the acceptance firing are discussed in drawing 1B71775E, Test Plan, Acceptance Firing, S-IVB/SV-STC. Significant configuration changes to the stage and GSE for the acceptance firing are discussed in the following paragraphs.

3.1.1 Propulsion System

a. Stage propellant vent and bleed systems were connected to the facility vent system. The nozzles were removed from the LH2 tank continuous vent system and the LOX and LH2 nonpropulsive vent systems.

b. The stage portions of the propellant and pneumatic quick-disconnects were replaced with hardlines.

c. A converging water-cooled diffuser was installed in the engine thrust chamber exit to reduce the possibility of sideloads induced by jet stream separation.

d. A GN2 ejector system was used to provide low pressure environment at the O_2-H_2 burner nozzle exit.

e. A heated GN2 purge was used for the LOX dome to prevent injector icing during the simulated orbital coast.

3.1.2 Propellant Utilization System

The propellant loading fast-fill sensors installed on the instrumentation probes were used in the indicating mode only.

3.1.3 Electrical Power System

a. Model DSV-4B-134 battery simulators were used to supply stage internal power.

b. Model DSV-4B-727 primary battery simulators were used in place of primary flight batteries.

3.1.4 Electrical Control System

a. The instrument unit and S-IVB/V stage electrical interfaces were simulated by GSE.

b. Two Model DSV-4B-188B APS simulators were used to provide APS module electrical loads to the stage control signals.

c. The electrical umbilicals remained connected throughout the acceptance firing.

3.1.5 Data Acquisition System

a. The MSFC Basic Static Firing Measurement Program hardwire transducers were installed.

b. All instrumentation parameters without transducers, and those disconnected for hardwire usage, were left as open channels.

3.1.6 Forward Skirt Environmental Control System

Coolant for the forward skirt thermoconditioning system was supplied by Model DSV-4B-359 Servicer.

3.1.7 Secure Range Safety Command System

a. The Engine Cutoff Command output from Range Safety Systems 1 and 2 was disconnected and stowed.

b. Pulse sensors were attached to the output of the exploding bridgewire (EBW) firing units.

3.1.8 Structural Systems

a. The main and auxiliary tunnel covers were not installed.

b. The stage was mounted on the Model DSV-4B-540 Dummy Interstage.

3.1.9 GSE and Facilities

a. Resistance wire fire detection system was installed for monitoring critical areas of the stage, GSE, and facilities

b. GH2 leak detection system was installed for monitoring critical areas of the stage, GSE, and facilities.

c. Blast detectors were installed in the test area for monitoring ranges of 0 to 25 psi overpressure.

d. Model 742 static firing hazardous gas shield, thrust cone water spray Firex, cryogenic spill pan, forward skirt support ring, and vent port covers were installed.

e. Model 601 flame resistant protective firing cover was installed to enclose the forward skirt area.

f. An auxiliary propellant tank pressurization system was installed using a GSE ambient helium source.

g. Model DSV-4B-618 Engine Unlatch Restrainer Links were installed to restrain the J-2 engine during start transient sideloads.

TABLE 3-1

S-IVB-509 STAGE AND GSE ACCEPTANCE FIRING ORIFICES

Description	Orifice Size or Nominal Flowrate	Coefficient of Discharge	Effective Area (in^2)
Stage			
Continuous vent bypass valve actuation control module inlet	0.017 in. dia	--	N/A
Continuous vent bypass valve bellows purge	300 scim with 3,000 psid	--	Sintered
Continuous vent bypass valve switch cavity purge	15 scim with 3,000 psid	--	Sintered
Continuous vent No. 1	1.090 in. dia	--	N/A
Continuous vent No. 2	1.090 in. dia	--	N/A
Continuous vent purge	1 scfm with 3,200 psid	--	Sintered
LH2 fill and drain valve	15 scim with 3,200 psid	--	Sintered
LOX fill and drain valve purge	15 scim with 3,200 psid	--	Sintered
LH2 chilldown valve purge	65 scfm with 1,600 psid	--	Sintered
LOX tank pressurization module, heat exchanger primary	0.219 in. dia	0.86	0.0327*
LOX tank pressurization module, heat exchanger bypass	0.1774 in. dia	0.90	0.02232*
LH2 tank pressurization--step mode (All three orifices used for acceptance firing only.)	--	--	0.1420*
LH2 tank pressurization module--overcontrol - second burn	0.2056 in. dia	**	0.1127*
LH2 tank pressurization module normal--undercontrol	0.3551 in. dia	**	0.0847

* Discharge coefficient and effective area are calculated for overcontrol and step orifices in combination with the undercontrol orifice.

** Not recorded during calibration

Table 3-1 (Continued)

Description	Orifice Size or Nominal Flowrate	Coefficient of Discharge	Effective Area (in^2)
LH2 tank pressurization module control--overcontrol first burn	0.2058 in. dia	*	0.1140**
LH2 tank pressurization module outlet	0.3126 in. dia	0.86	0.0665
O2-H2 burner LH2 supply valve purge	15 scim with 3,200 psid	--	Sintered
LH2 tank nonpropulsive vent purge	1 scfm with 3,200 psid	--	Sintered
LH2 tank nonpropulsive vent No. 1	2.180 in. dia	--	N/A
LH2 tank nonpropulsive vent No. 2	2.180 in. dia	--	N/A
LOX chilldown pump purge	37 scim with 475 psid	--	Sintered
LOX sensing line purge	1 scfm with 3,200 psid	--	Sintered
O2-H2 burner GH2 balance, injector No. 1	0.550 in. dia	--	--
O2-H2 burner GH2 balance, injector No. 2	0.550 in. dia	--	--
O2-H2 burner LH2 tank pressurization coil outlet	0.221 in. dia	--	0.03334
LOX tank vent and relief valve purge	65 scfm with 3,000 psid	--	Sintered
O2-H2 burner LH2 tank pressurization coil helium inlet balance	0.120 in. dia	0.88	0.00999
O2-H2 burner LOX tank pressurization coil outlet	0.089 in. dia	0.91	0.00565
LOX tank ambient repressurization module outlet	0.1137 in. dia	--	0.00878
Engine purge control module	6 scfm	--	0.00028

* Not recorded during calibration

** Discharge coefficient and effective area are calculated for overcontrol and step orifices in combination with the undercontrol orifice.

Table 3-1 (Continued)

Description	Orifice Size or Nominal Flowrate	Coefficient of Discharge	Effective Area (in^2)
Console A			
All console A stage bleeds	Variable	--	--
Pressure actuated valve and main-stage pressure switch supply	1.2 scfm	--	Sintered
J-2 box inerting supply	0.013 in. dia	--	--
LH2 system checkout supply	1.2 scfm	--	Sintered
LOX system checkout supply	2.0 scfm	--	Sintered
LH2 tank and umbilical purge supply	0.260 in. dia	0.88	0.0468
Pressure switch checkout-Low pressure	1.2 scfm	--	Sintered
Pressure switch checkout-High pressure	0.044 in. dia	0.91	0.00139
LH2 tank repressurization supply	Union	--	--
Console GN2 inerting supply	0.013 in. dia	--	--
Console B			
All console B stage bleeds	Variable	--	--
LOX tank repressurization supply	0.114 in. dia	0.88	0.[illegible]98
Turbine start sphere supply	Union	--	--
LOX tank prepressurization supply	0.096 in. dia	0.94	0.00680
Console GN2 inerting supply	Variable	--	--
Engine control helium sphere supply	0.125 in. dia	0.83	0.0102
LH2 tank prepressurization supply	0.161 in. dia	0.83	0.0169
Thrust chamber jacket purge and chilldown supply	0.072 in. dia	0.91	0.00370
LOX tank and umbilical purge supply	0.302 in. dia	0.89	0.0635
J-2 box inerting supply	0.013 in. dia	--	--

Table 3-1 (Continued)

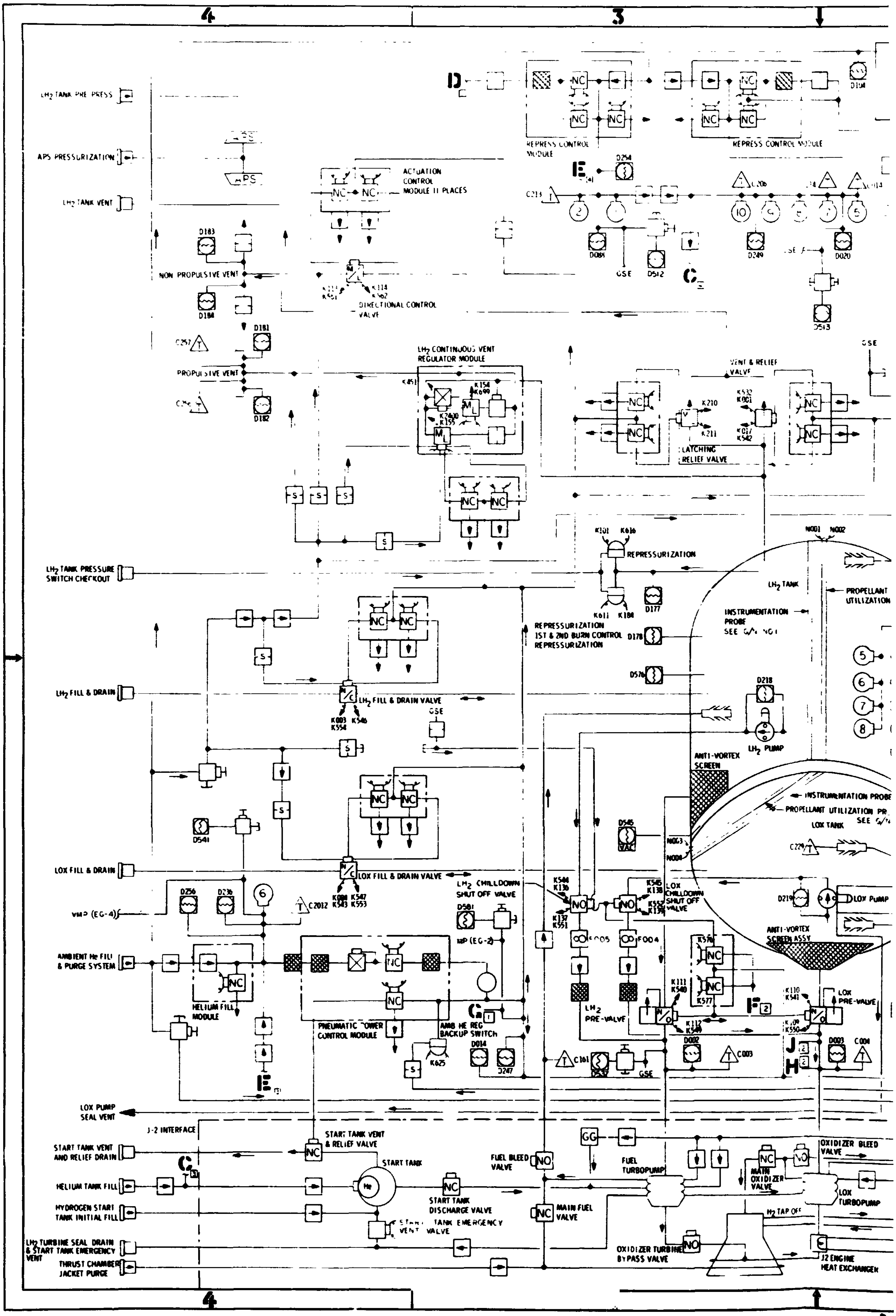
Description	Orifice Size or Nominal Flowrate	Coefficient of Discharge	Effective Area (in^2)
Turbine start sphere supply vent	0.081 in. dia	0.83	0.00479
LOX tank auxiliary pressure	0.2517 in. dia	0.94	0.0465
LH2 tank auxiliary pressure	0.385 in. dia	0.91	0.1060

TABLE 3-2

S-IVB-509 STAGE PRESSURE SWITCH DATA

Name	Part No. and Serial No.	Specification (psia)			Prefire Checkout* (psia)		
		Pickup	Dropout	Deadband	Pickup	Dropout	Deadband
Engine pump purge	1B52623-515 S/N 022	136 max	99 min	3.0 min	122.017	110.621	11.396
Control helium regulator backup	1B52624-517 S/N 026	600 ±21	490 ±31	--	598.609	498.117	--
Cold helium regulator backup	1B52624-519 S/N 59	467.5 ±22.5	362.5 ±33.5	--	467.550	368.601	--
LOX flight control and ground fill	1B52624-515 S/N 53	41 max	37.5 min	0.5 min	40.058	39.101	0.957
LH2 first burn and flight control	1B52624-511 S/N 036	31.5 max	27.8 min	0.5 min	30.424	29.184	1.240
LH2 second burn, ground fill and prepressurization	1B52624-511 S/N 037	31.5 max	27.8 min	0.5 min	30.393	28.966	1.426
LOX repressurization backup	1B52624-519 S/N 46	467.5 ±22.5	362.5 ±33.5	--	473.508	368.344	--
LH2 repressurization backup	1B52624-519 S/N 45	467.5 ±22.5	362.5 ±33.5	--	467.523	376.633	--
Mainstage OK No. 1	308390 S/N 25568A	515 ±36	Pickup minus 75 +56, -31	--	505.843	429.820	76.023
Mainstage OK No. 2	308390 S/N 25573A	515 ±36	Pickup minus 75 +56, -31	--	514.160	451.230	62.930

* These values are the average of three actuations.



FOLDOUT FRAME 1

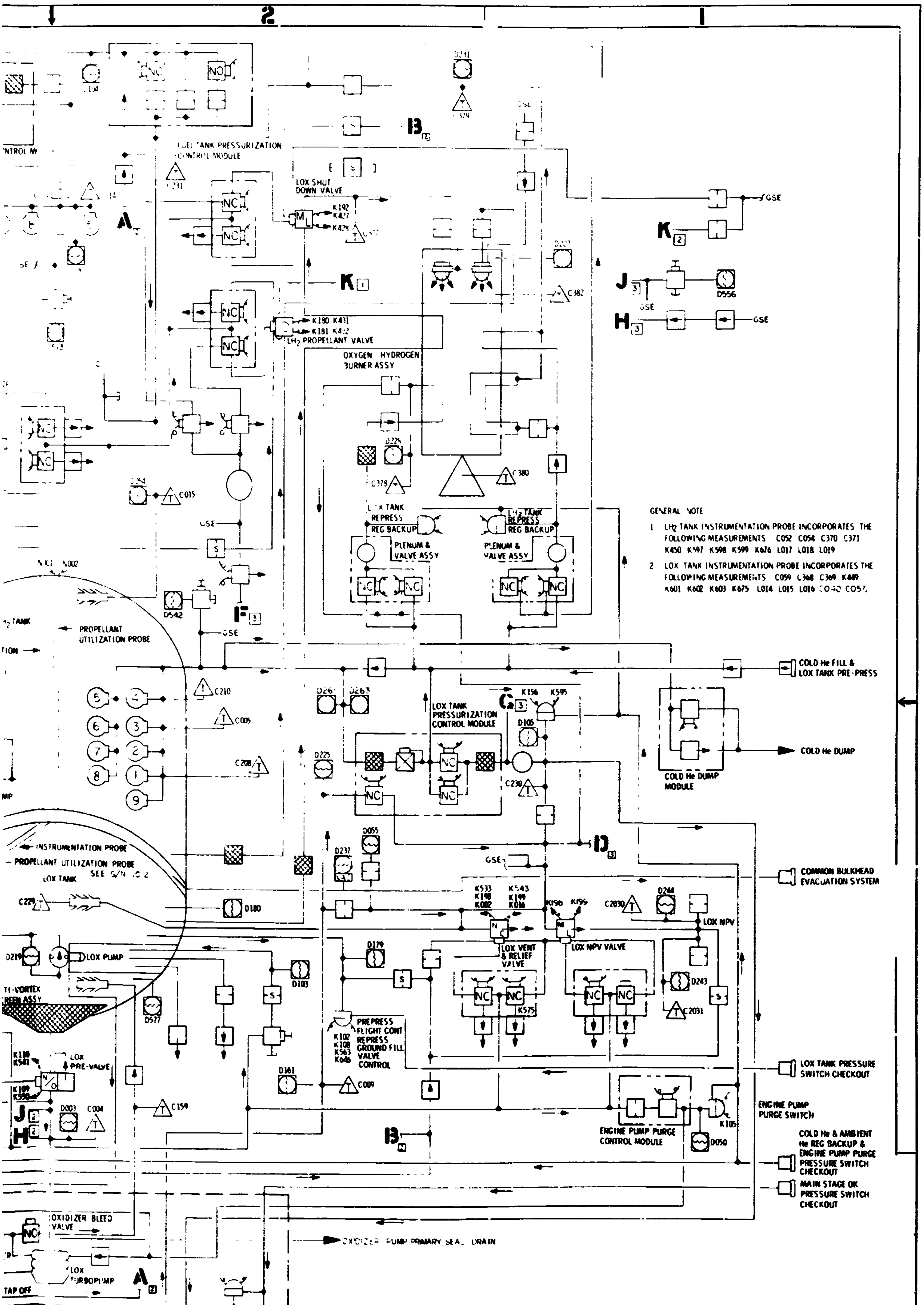


Figure 3-1. Propulsion System and Instrumentation

FOLDOUT FRAME 2

4. TEST OPERATIONS

The S-IVB-509 stage was the ninth of the basic S-IVB/V series to be successfully acceptance tested. The acceptance firing was preceded by an O2-H2 burner firing and an ambient repressurization test. Details of the countdown and checkout (precountdown) activities are presented in the following paragraphs. Significant events occurred at the following times:

Event	Time (PDT)
O2-H2 burner firing initiation	1134:53.445
Simulated liftoff	1400:48.000
Engine start command	1409:18.981
Engine cutoff command	1416:54.316

4.1 Checkout

After the S-IVB-509 stage was assembled at the McDonnell-Douglas (MDAC) Astronautics Company Space Systems Center in Huntington Beach, it was subjected to a complete stage checkout including an all systems test. It was then modified and shipped to the Sacramento Test Center (STC). It arrived at STC on 1 April 1969 and was installed in Beta Complex Test Stand III. The modification program continued concurrently with stage checkout. All modifications were completed before the integrated systems test which was satisfactorily accomplished on 30 April.

A practice countdown was conducted on 7 and 8 May for software verification and countdown crew training. The "Ready for Acceptance Firing" milestone was met on 12 May. The prefiring and postfiring checkouts were performed in accordance with the established handling and checkout procedures.

4.2 Countdown Operations

The acceptance firing, countdown 614120, was a full duration J-2 engine firing initiated on 13 May 1969 at 0830 PDT. Shortly after LOX loading started, a 40-minute hold was called because the low pressure GN2 vaporizer failed to reignite. The hold and other noteworthy events are discussed in paragraph 4.3. The acceptance firing was successfully completed on 14 May.

Except for the deviations necessitated by a single J-2 engine burn, the performance of an O2-H2 burner firing, and the ambient repressurization test, the countdown conformed to the sequence intended for use at Kennedy Space Center. Significant events during these operations are listed in tables 4-1, 4-2, and 4-3. The propulsion operations were performed in the following sequence:

a. Propellants were loaded to the 68 percent level.
b. LOX and LH2 tank vent relief test was performed.
c. The continuous vent valve was functionally tested.
d. The O2-H2 burner firing was performed.
e. The ambient repressurization system was functionally tested.
f. The LOX and LH2 tanks were reloaded to the 100 percent level.
g. The terminal countdown and J-2 engine firing were performed.

The LOX and LH2 systems relieved at the following pressures:

Valve	Pressure (psia)		
LOX NPV	43.2	43.1	43.1
LOX vent and relief	Not obtained		
LH2 latching relief	32.2	32.2	32.0
LH2 vent and relief	Not obtained		

The firing of the restartable O2-H2 burner was initiated at 1134:53 PDT and proceeded normally through burner shutdown. The burner firing was 455 seconds, as programmed.

4.2.1 Cryogenic Loading

Setups for LOX loading began at 0600 PDT on 13 May, and both tanks were loaded to the 68 percent level by 0907 PDT. The on-stand inspection was then accomplished, and the burner and ambient repressurization tests were performed. The tanks were then reloaded to the 100 percent level.

4.2.2 Terminal Countdown

The terminal countdown was initiated at 1340:18 PDT (T -20 minutes 30 seconds). The count proceeded smoothly through J-2 engine cutoff which was initiated by the LH2 depletion sensor at T +966 seconds. Mainstage duration was 452 seconds.

4.3 Noteworthy Events

The following noteworthy events occurred during the countdown:

a. During LOX loading, a 40-minute hold was called because the facility low pressure GN2 vaporizer failed to ignite on a relight cycle. It was manually started and operated normally during J-2 engine firing and vehicle off-loading.

b. After LOX reload to the 100 percent level, the LOX fill and drain valve required boost command to close.

c. At initiation of LH2 and LOX relief tests, the cold helium shutoff valves energized talkback (K0571) failed to pick up in the allowable 26 milliseconds and caused a program halt. The steps were repeated once with the same result, then again slowly and successfully. The problem was attributed to slow dropout of the relay in the GSE. Programmed timing for this item was considered marginal, and it will be extended for the next test.

d. During critical components cycling, engine control sphere pressure (D0534) was thought to have increased during engine control sphere dump cycle. Actually, when the cold helium sphere fill supply valve was opened at approximately 3 seconds before the engine control sphere dump cycle, the sudden large demand for helium caused an approximately 80-psi increase in the stage helium regulator outlet pressure and a corresponding increase in the engine control sphere pressure.

e. The LOX fast fill sensor wet condition talkback (K0675), which is located at the 98 percent mass level, failed to pick up during LOX loading to the 100 percent level and remained off until it was jarred by the vibrations at engine start command. The connector back-shell at the tank feedthrough to the sensor was found loose during post-test inspection.

f. During execution of the propellant dispersion subroutine, which is run 21 seconds after engine start command, range safety system No. 2 did not function properly because of a faulty decoder. The decoder was replaced.

4.4 Atmospheric Conditions

The following atmospheric conditions prevailed during the countdown:

Time (PDT)	0920	1533
Wind speed (knots)	3	2
Wind direction (deg from North)	180	280
Barometric pressure (in. Hg)	29.97	29.91
Ambient temperature (deg F)	58	N/A
Dew point (deg F)	46	47

TABLE 4-1

O2-H2 BURNER SEQUENCE OF EVENTS

Time (sec)	Meas. No.	Event
-9.468	K0532	LH2 tank vent valve closed
0.0	K0431	Burner ignition sequence initiated--Burner LH2 propellant valve opened (11:34:53.423 PDT)
0.717	K0427	Burner LOX propellant valve opened
0.873	K0699	LH2 tank vent relief overboard valve closed
0.976	K2400	LH2 tank vent orifice bypass valve closed
2.876	K0452	LH2 tank vent orifice and relief reset
4.040	K0437	O2-H2 burner system relay reset
6.741	K0438	O2-H2 voting circuit enabled
6.858	K0443	LH2 tank repressurization valve opened
7.040	K0444	LOX tank repressurization valve opened
177.235	K0443	LH2 tank repressurization valve closed
177.236	K0616	LH2 tank overpressurization pressure switch energized
177.465	K0444	LOX tank repressurization valve closed
207.751	K0519	LOX chilldown pump/inverter energized
212.807	K0512	LH2 chilldown pump/inverter energized
217.984	K0576	LH2 and LOX prevalves closed
408.729	K0524	LH2 tank flight pressure valve energized
408.729	K0523	LH2 tank step pressurization valve energized
455.436	K0432	LH2 propellant valve closed
455.562	K0441	LH2 and LOX repressurization system reset
455.563	K0438	O2-H2 voting circuit disabled
456.177	K0440	LH2 and LOX repressurization mode - ambient
457.806	K0452	LH2 tank vent orifice and relief reset off
458.412	K0437	O2-H2 burner system relay reset
459.988	K0428	Burner LOX propellant valve closed
518.765	K0544	LH2 chilldown shutoff valve opened
520.154	K0541	LOX prevalve opened
520.289	K0540	LH2 prevalve opened
528.071	K0641	LH2 chilldown pump relay reset
528.279	K0644	LOX chilldown pump relay reset
529.525	K0621	Hydraulic auxiliary pump flight relay reset

TABLE 4-2

AMBIENT REPRESSURIZATION SEQUENCE

Time (sec)	Meas. No.	Event
-163.527	K0543	LOX tank vent valve closed
0.0	K0444	Ambient repressurization sequence initiated--LOX tank repressurization valve opened (11:46:53.755 PDT)
4.550	K0699	LH2 tank vent relief overboard valve closed
4.647	K2400	LH2 tank vent orifice bypass valve closed
20.490	K0443	LH2 tank repressurization valve opened
52.110	K0443	LH2 tank repressurization valve closed
52.111	K0616	LH2 tank overpressure pressure switch energized
81.419	K0444	LOX tank repressurization valve closed
81.421	K0563	LOX tank overpressure pressure switch energized
109.292	K2429	LH2 tank latch and relief valve opened
156.259	K0466	LOX tank NPV valve opened

TABLE 4-3

S-IVB-509 ACCEPTANCE FIRING SEQUENCE

Time (sec)	Meas. No.	Event
-874.664	K2881	Engine start tank purge supply closed
-870.552	K2853	Engine start tank chilldown and fill initiated
-408.529	K2888	Engine thrust chamber chilldown initiated
-330.334	K3885	Start tank vent closed
-327.490	K2852	Engine start tank fill terminated
-299.437	K2892	Engine control sphere fill terminated
-299.192	K0512	LH2 chilldown pump ON
-289.277	K0519	LOX chilldown pump ON
-284.095	K0576	LOX and LH2 prevalve closed command
-283.979	K0540	LH2 prevalve open position dropped out
-283.971	K0541	LOX prevalve open position dropped out
-283.626	K0549	LH2 prevalve closed position picked up
-283.616	K0550	LOX prevalve closed position picked up
-209.463	K2424	LOX NPV latched
-165.909	K0533	LOX vent valve closed
-164.241	K0571	LOX tank prepressurization initiated
-153.002	K0571	LOX tank prepressurization terminated
-147.887	K0571	LOX tank prepressurization makeup cycle initiated
-147.182	K0571	LOX tank prepressurization makeup cycle terminated
-132.784	K0571	LOX tank prepressurization makeup cycle initiated
-132.151	K0571	LOX tank prepressurization makeup cycle terminated
-96.111	K0532	LH2 tank vent valve closed
-94.656	K2897	LH2 tank prepressurization initiated
-43.053	K2897	LH2 tank prepressurization terminated
-26.610	K0562	LH2 directional vent valve to flight position
-8.294	K3705	Cold helium supply vent opened
-8.239	K2870	LH2 tank prepressurization supply vent opened
0.0		Simulated liftoff (14:00:48.000 PST)
488.115	K2889	Engine thrust chamber chilldown terminated
506.925	K0576	LH2 and LOX prevalve open command

Table 4-3 (Continued)

Time (sec)	Meas. No.	Event
507.660	K0550	LOX prevalve closed position dropped out
507.810	K0549	LH2 prevalve closed position dropped out
508.597	K0571	Cold helium shutoff valves opened
509.076	K0541	LOX prevalve open picked up
509.236	K0540	LH2 prevalve open picked up
510.287	K0519	LOX chilldown pump OFF
510.378	K0512	LH2 chilldown pump OFF
510.981	K0556	Engine start command
510.983	K0531	Engine control helium valve opened
511.047	K0627	LOX ASI valve opened
511.054	K0632	Main LH2 valve started to open
511.098	K0466	LOX tank vent valve opened
511.109	K0557	LH2 bleed valve closed
511.124	K0558	LOX bleed valve closed
511.133	K0458	Main LH2 valve opened
512.111	K0536	Start tank discharge valve open command
512.269	K0695	Start tank discharge valve started to open
512.327	K0460	Start tank discharge valve opened
512.563	K0536	Start tank discharge valve close command
512.651	K0633	Main LOX valve started to open
512.663	K0631	Gas generator valve started to open
512.694	K0460	Start tank discharge valve started to close
512.783	K0457	Gas generator valve opened
512.907	K0695	Start tank discharge valve closed
513.964	K0524	LH2 tank flight pressure valve close command
513.964	K0523	LH2 tank step pressurization valve close command
514.750	K0459	Main LOX valve opened
514.752	K0466	LOX tank vent valve closed
514.904	K2431	LH2 latching vent valve opened
531.997	K2432	J-2 heat exchanger bypass valve closed override disabled (valve closed)
752.044	K2431	LH2 latching vent valve closed

Table 4-3 (Continued)

Time (sec)	Meas. No.	Event
861.308	K0524 K0523	LH2 tank flight pressurization second burn mode initiated
921.193	K0523 K0524	LH2 tank step pressurization initiated
921.436	K0577	LH2 and LOX chilldown shutoff valve close command
921.595	K0544	LH2 chilldown shutoff valve open dropped out
921.606	K0545	LOX chilldown shutoff valve open dropped out
921.646	K0552	LOX chilldown shutoff valve closed picked up
921.684	K0551	LH2 chilldown shutoff valve closed picked up
928.621	K2431	LH2 tank latching vent valve closed dropped out
951.834	K0532	LH2 vent valve opened
966.316	K0522	Engine cutoff command

5. SEQUENCE OF EVENTS

The S-IVB-509 acceptance firing sequence of events is presented in table 5-1, and the O_2-H_2 burner firing sequence of events is presented in table 5-2. The two time bases used in this table are as follows:

O_2-H_2 Burner Ignition Sequence	1134:54.000 hr PDT
Simulated Liftoff for J-2 Engine Firing	1400:48.000 hr PDT

The data sources were the Digital Events Recorder (DER/CAT 57) and the PCM/FM System (CAT 42). Accuracies of the listed events are as follows:

Data Source	Accuracies
Digital Events Recorder (DER/CAT 57)	+0, -1 ms
PCM/FM	
Discrete Bilevel (CAT 42)	
Direct Inserted	+0, -9 ms
Submultiplexed	+0, -84 ms

TABLE 5-1 (Sheet 1 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Launch Automatic Sequence Start (J-2 Eng. Firing Phase)					
S-IVB Engine Cutoff	12	K3890	-478.490		
Eng Cutoff Lockin Indication - On		K0539	-478.476		
Eng Cutoff Command - On		K0418	-478.478	K0140	-478.472
Eng Cutoff Ind - On		K0522	-478.474	K0013	-478.439
Eng Ign Bus Pwr On Cmd - On	GSE	K3819	-478.260		
Eng Ign Bus Pwr Ind - On		K0630	-478.203		
Aux Hyd Pump Flt Mode On	28	K3890	-477.423		
Aux Hyd Pump Flt Rel Reset - Off		K0621	-477.420		
Aux Hyd Pump Power On		K0513	-477.336		
Eng St Tk Dump Close	GSE	K3885	-330.334		
Start Tk GH_2 Vent Cls Cmd - Off	GSE	K2856	-32[illegible].459		
St Tk GH_2 Vent Cls Ind - Off		K2854	-327.399		
St Tk GH_2 Vent Open Ind - On		K2855	-327.391		
LH_2 Chilldown Pump On	58	K3890	-299.200		
LH_2 C/D Pump Rel Reset - Off		K0641	-299.206		
LH_2 C/D Pump Inverter On		K0512	-299.192		

GSE = This event indicates that a particular command has been sent from Ground Support Equipment to the stage.

TABLE 5-1 (Sheet 2 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX Childown Pump On	22	K3890	-289.186		
LOX C/D Pump Rel Reset - Off		K0644	-289.179		
LOX C/D Pump Inverter On		K0519	-289.177		
LOX & LH_2 Prevalve Close Command - On	GSE	K0576	-284.095		
LH_2 Prevalve Open Indication - Off		K0540	-283.979	K0111	-283.964
LOX Prevalve Open Indication - Off		K0541	-283.971	K0109	-283.964
LH_2 Prevalve Closed Indication - On		K0549	-283.626	K0112	-283.631
LOX Prevalve Closed Indication - On		K0550	-283.616	K0110	-283.547
APS Bus Pwr - Cmd On	GSE	K3774	-219.987		
APS Bus 1 Pwr Ind - On		K0619	-219.934		
APS Bus 2 Pwr Ind - On		K0620	-219.934		
Heat Exchanger Bypass Valve Control Disable (Preflight Command Only)	51	K3890	-209.608		
Heat Exchanger Bypass Valve Disable - On		K2432	-209.600		
LOX Tk NPV Vlv Latch Open Off	45	K3890	-209.473		
LOX Tk Vents Bst Close and Latch Rels - On	GSE	K2424	-209.463		
LOX Tank Vent Valve Open Ener - Off		K0575	-166.300		

TABLE 5-1 (Sheet 3 of 20)
SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX Tank Vent Vlv Open Indication - Off		K0543	-166.074	K0016	-166.067
LOX Tank Vent Valve Closed Indication - On		K0533	-165.909	K0002	-165.892
Cold He Shutoff Valve Close Command - Off (Open)	GSE	K3802	-164.249		
Cold He Shutoff Valve Ener Indication - On		K0571	-164.241		
LOX Tk Overpress P/S Ener		K0563	-153.008	K0102	-152.976
Cold He Shutoff Valve Ener Ind - Off		K0571	-153.002		
LH_2 Tank Vent Valve Command - Off (Close)	GSE	K3839	-96.810		
LH_2 Tank Vent Valve Open Ener - Off		K0516	-96.808		
LH_2 Tank Vent Valve Close Ind - On		K0532	-96.111	K0001	-96.073
LH_2 Tank Vent Valve Open Ind - Off		K0542	-96.470	K0017	-96.489
LH_2 Latch Rlf Vlv Open Latch Cmd - Off	GSE	K5842	-94.699		
LOX Tank Fill & Drain Vlv Cmd - Off	GSE	K3846	-85.187		
LOX Tank Fill & Drain Bst Close - On	GSE	K3845	-85.174		
LOX Tank Fill & Drain Open Indication - Off		K0547	-84.705		
LOX Tank Fill & Drain Closed Indication - On		K0553	-84.102	K0004	-84.074

TABLE 5-1 (Sheet 4 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX Tank Fill & Drain Bst Close - Off	GSE	K3845	-83.101		
LH_2 Tank Fill & Drain Vlv Cmd - Off	GSE	K3832	-83.912		
LH_2 Tank Fill & Drain Bst Close - On	GSE	K3831	-83.072		
LH_2 Tank Fill & Drain Open - Off		K0546	-82.607		
LH_2 Tank Fill & Drain Closed Indication - On		K0554	-81.905	K0003	-81.824
LH_2 Tank Fill & Drain Bst Close - Off	GSE	K3831	-81.024		
Aft Bus 1 Transfer Internal Indication - On	GSE	K0622	-49.691		
Aft Bus 2 Transfer Internal Indication - On	GSE	K0623	-49.443		
Fwd Power Internal Indication - On	GSE	K0639	-49.194		
LH_2 Tank Vent Dir Gnd Position Off	GSE	K0561	-26.756	K0113	-26.737
LH_2 Tank Vent Dir Flight Position On	GSE	K0562	-26.610	K0114	-26.570
R/S 1 PD Cutoff Cmd Inhibit Indication - Off	GSE	K0662	-8.207		
R/S 2 PD Cutoff Cmd Inhibit Indication - Off	GSE	K0661	-8.175		

TABLE 5-1 (Sheet 5 of 20)
SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Simulated Liftoff (T_0)*			000.000		
Coast Period On - Cmd	79	K3890	002.586		
LOX Flt Press Coast Period Rst - Ind - Off		K0416	002.589		
T/M Calibration On	62	K3890	116.116		
T/M Calibration Off	63	K3890	117.280		
Eng Pump Prg Cont Valve Enable On	24	K[illegible]0	330.346		
Eng Pump Prg Sol Valve Energized		K0566	330.3[illegible]		
Coast Period Off - Cmd	80	K3890	334.250		
LOX Flt Press Coast Period Rst - Ind - On		K0416	334.254		
Eng Cutoff Arm - Observer	GSE	K5811	334.367		
Eng Pump Prg Cont Valve Enable Off	25	K3890	450.473		
Eng Pump Prg Sol Valve De-energized		K0566	450.487		
T/M Calibration On	62	K3890	451.635		
T/M Calibration Off	63	K3890	452.749		
Charge Ullage Ignition On	54	K3890	506.782		
Ullage Rkt Pilot Relays Rst - Off		K0673	506.789		
LH2 & LOX Prevlv Cls Cmd - Off	GSE	K3867	506.923		
LH_2 & LOX Prevalve Open Command - On	.	K0576	506.925		

*T_0 = 1400:48.000 PDT

TABLE 5-1 (Sheet 6 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX Prevalve Closed Indication - Off		K0550	507.660	K0110	507.716
LH_2 Prevalve Closed Indication - Off		K0549	507.810	K0112	507.883
LOX Prevalve Open Indication - On		K0541	509.076	K0109	509.132
LH_2 Prevalve Open Indication - On		K0540	509.236	K0111	509.298
LOX Tk Flt Press Syst On	103	K3890	508.583		
Cold He Shutoff Valve Ener Ind - On		K0571	508.597		
LOX Chilldown Pump Off	23	K3890	510.282		
LOX C/D Pump Inverter Off Indication		K0519	510.287		
LOX C/D Pump Rel Reset Indication		K0644	510.289		
LH_2 C/D Pump Off	59	K3890	510.373		
LH_2 C/D Pump Inverter Off Indication		K0512	510.378		
LH_2 C/D Pump Rel Reset Indication		K0641	510.380		
S-IVB Engine Cutoff Off	13	K3890	510.552		
Engine Cutoff Ind - Sw Sel Reset		K0418	510.537	K0140	510.607
Engine Cutoff Indicator - De-energized		K0522	510.540		

TABLE 5-1 (Sheet 7 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Aft Separate Simu 1 On	GSE	K4790	510.586		
Aft Separate Simu 2 On	GSE	K5714	510.613		
Fire Ullage Ign On	56	K3890	510.674		
Ullage Rkt Ign PS 1 Indication				K0176	510.732
Ullage Rkt Ign PS 2 Indication				K0177	510.732
S-IVB Engine Start On	9	K3890	510.978		
Engine Start Command Rel Rst Off		K0634	510.980		
Engine Start Command On		K0556	510.981	K0021	510.980
Eng Ign Ph Cont Sol Ener		K0535	510.983	K0006	510.988
Eng Spark T/C Sys On		K0454	510.983	K0010	510.988
Eng Spark GG Sys On		K0455	510.983	K0011	510.988
Eng Cont He Sol Valve Ener		K0531	510.983	K0007	510.988
Eng Ready Sig Off		K0530	510.986	K0012	511.057
Eng ASI LOX Valve Open		K0627	511.047		
Eng Main LH_2 Vlv Cls - Off		K0632	511.054		
LOX NPV Vlv Clsd Ind - On			511.098		
Eng LH_2 Bld Valve Cls - On		K0557	511.109		
Eng Main LH_2 Vlv Open - On		K0458	511.133	K0118	511.140
Eng LOX Bld Vlv Cls - On		K0558	511.124		
Eng Ign Detected		K0537	511.178	K0008	511.180

TABLE 5-1 (Sheet 8 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Aft Separate Simu 1 Off	GSE	K4790	511.326		
Aft Separate Simu 2 Off	GSE	K5714	511.334		
Fuel Inj Temp OK Bypass	11	K3890	512.101		
Fuel Inj Temp OK Bypass Rly Reset		K0446	512.107		
Engine Start Tk Disch Cont Sol Ener		K0536	512.111	K0096	512.113
Engine Start Tk Disch Vlv Clsd Ind - Off		K0695	512.269		
Eng St Tk Disch Vlv Opn - On		K0460	512.327	K0122	512.390
Eng St Tk Disch Sol Ener - Off		K0536	512.563	K0096	512.563
Eng M/S Cont Sol Ener - On		K0538	512.564	K0005	512.563
Eng Main LOX Vlv Cls Ind - Off		K0633	512.651		
Eng GG Vlv Cls Ind - Off		K0631	512.663		
Eng St Tk Disch Vlv Opn - Off		K0460	512.694	K0122	512.723
Eng GG Vlv Opn - On		K0457	512.783	K0117	512.807
Eng LOX Turb Byp Vlv Open - Off		K0461	512.810	K0124	512.815
Eng St Tk Disch Vlv Cls Ind - On		K0695	512.907		
F LOX Turb Byp Vlv Closed - On		K0463	513.008	K0125	513.065

TABLE 5-1 (Sheet 9 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng M/S OK Press Sw-1		K0610	514.242	K0014	514.270
Eng M/S OK P/S-1 Pressurized		K0572	514.243	K0158	514.249
Eng M/S OK Press Sw Pick-up (No)		K0412	514.244		
Eng M/S OK Press Sw Pick-up (No)		K0685	514.244		
Eng M/S OK P/S-2 Pressurized		K0573	514.244	K0159	514.249
Eng M/S OK P/S-2 Pressurized				K0157	514.249
Eng Main LOX Vlv Open		K0459	514.750	K0120	514.807
Eng Spark GG Sys - Off		K0454	515.865	K0010	515.871
Eng Spark T/C Sys - Off		K0455	515.865	K0011	515.871
S-IVB Engine Start Off	27	K3890	512.308		
Engine Start Command Rel Rst		K0634	512.312		
Engine Start Command Off		K0556	512.314	K0021	511.338
First Burn Relay On	68	K3890	513.954		
First Burn Press Cont Vlv Sol Ener		K0524	513.964		
First Burn Step Press Cont Vlv Ener		K0523	513.964		
PU Activate On	5	K3890	517.142		
PU Activated		K0507	517.147		

TABLE 5-1 (Sheet 10 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Chg Ullage Jett On	55	K3890	518.632		
Fire Ullage Jett On	57	K3890	521.152		
Ullage Rocket Jett P/S 1 Ind - On				K0149	521.239
Ullage Rocket Jett P/S 2 Ind - On				K0150	521.239
Fuel Inj Temp OK Bypass Reset	16	K3890	522.381		
Eng LH_2 Inj Temp Byp Rst		K0446	522.390		
Ullage Rocket Chg Reset	88	K3890	524.516		
Ullage Rocket Firing Reset	73	K3890	524.742		
Ullage Rocket Pilot Relays Rst		K0673	524.750		
Ht Exch Bypass Valve Control Enable	50	K3890	531.991		
LOX Press Ht Exch Bypass Vlv Cont Disable - Off		K2432	531.997		
R/S EBW FU Arm & ECO Cmd - On	GSE	K5758	535.433		
R/S 2 Arm & ECO Cmd Rcvd		K0659	*		
R/S 1 Arm & ECO Cmd Rcvd		K0660	535.538		
R/S 2 PD EBW FU Pwr On		K0651	*		
R/S 1 PD EBW FU Pwr On		K0650	535.541		
R/S 2 EBW Arm & ECO On		K0692	*		
R/S 1 EBW FU Arm & ECO - On		K0693	535.546		

*R/S Sys 2 Failed to Operate during the Firing

TABLE 5-1 (Sheet 11 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RECEIPT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
R/S 2 Arm & ECO Cmd Rcvd Off		K0659	*		
R/S 1 Arm & ECO Cmd Rcvd - Off		K0660	535.565		
R/S EBW FU Arm & ECO Cmd - Off	GSE	K5758	535.681		
R/S PD Cmd - On	GSE	K5757	538.839		
R/S 2 PD Cmd Rcvd On		K2405	*		
R/S 1 PD Cmd Rcvd On		K2404	538.949	K0141	538.980
R/S 2 PD Cmd Rcvd Off		K2405	*		
R/S 1 PD Cmd Rcvd Off		K2404	538.976		
R/S PD Cmd - Off	GSE	K5757	539.092		
R/S Sys Off Cmd - On	GSE	K5759	542.168		
R/S 2 Sys Off Cmd Rcvd - On		K0679	*		
R/S 2 PD EBW FU Pwr Off		K0651	*		
R/S 2 Rcvr Pwr Off		K0678	*		
R/S 2 Sys Off Cmd Rcvd - Off		K0679	*		
R/S 1 Sys Off Cmd Rcvd - On		K0681	542.275		
R/S 1 Sys Off Cmd Rcvd - Off		K0681	542.277		
R/S 1 PD EBW FU Pwr Off		K0650	542.277		
R/S 1 Rcvr Pwr Off		K0680	542.277		

*R/S Sys 2 Failed to Operate during the Firing

TABLE 5-1 (Sheet 12 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
R/S Sys Off Cmd - Off	GSE	K5759	542.417		
Aux Hyd Pmp Flt Mode Off	29	K3890	656.128		
Aux Hyd Pmp Flt Rel Rst - Off		K0621	656.133		
Aux Hyd Pmp On Ener - Off		K0513	656.383		
Aux Hyd Pmp Flt Mode On	28	K3890	706.135		
Aux Hyd Pmp Flt Rel Reset - Off		K0621	706.139		
Aux Hyd Pmp Power On		K0513	706.226		
First Burn Relay Off	69	K3890	861.172		
Fuel Tank Press Cont Vlv Sol De-ener		K0524	861.179		
Fuel Tank Step Press Cont Vlv Sol De-ener		K0523	861.179		
Second Burn Relay On	32	K3890	861.300		
LH_2 Tk Step Pres Vlv Ener		K0523	861.308		
Fuel Tk Press Cont Vlv Sol Ener		K0524	861.308		
PU Active Off	6	K3890	861.407		
PU Sys On Indication		K0507	861.410		
PU Hardover On	17	K3890	861.541		
PU Opn Loop Rels Rst		K2440	861.547		

TABLE 5-1 (Sheet 13 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Second Burn Relay Off	33	K3890	921.186		
Fuel Tk Press Cont Vlv Sol De-ener		K0524	921.193		
LH_2 Tk Step Pres Vlv Ener		K0523	921.193		
PU Position Hardover Off	18	K3890	921.343		
LH_2 and LOX C/D Sov Cls Cmd - On	GSE	K3862	921.435		
LH_2 & LOX C/D Shutoff Close Ener - On		K0577	921.436		
LH_2 C/D Shutoff Valve Open - Off		K0544	921.595	K0137	921.646
LOX C/D Shutoff Valve Open - Off		K0545	921.606	K0138	921.654
LOX C/D Shutoff Valve Closed - On		K0552	921.646	K0139	921.654
LH_2 C/D Shutoff Valve Closed - On		K0551	921.684	K0136	921.729
Point Level Sensor Arming	97	K3890	962.903		
Eng Pump Purge Cont Vlv Enable On	24	K3890	962.993		
Eng Pump Prg Sol Vlv Ener - On		K0566	963.007	K0105	964.925
Eng Lkt Ct Pwr Cmd - On	GSE	K4796	966.315		
Eng Cutoff Lock-In Ind - On		K0539	966.316	K0013	966.350
Eng Ign Ph Cont Sol Ener - Off		K0535	966.316	K0006	966.323

TABLE 5-1 (Sheet 14 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng Cutoff Ind - Veh Ener - On		K0522	966.319		
Eng M/S Cont Sol Ener - Off		K0538	966.319	K0005	966.323
Eng Cutoff Ind - Non Prog - On		K0419	966.320		
Eng ASI Oxid Vlv Open		K0627	966.336		
Eng GG Vlv Open - Off		K0457	966.350	K0117	966.433
O_2-H_2 Burner Sys Rel Rst Ind - Off		K0437	966.321		
Eng Main LOX Vlv Open - Off		K0459	966.405	K0120	966.433
Eng GG Vlv Cls - On		K0631	966.408		
Eng Main LH_2 Vlv Open - Off		K0458	966.444	K0118	966.517
Eng M/S OK P/S-2 Depressurized		K0573	966.497	K0159	966.542
Eng M/S OK P/S-1 Depressurized		K0572	966.497	K0158	966.452
Eng M/S OK Press Sw No. 1 - Off		K0610	966.499	K0014	966.500
Eng Thrust OK 2		K0412	966.501		
Eng Thrust OK 1		K0685	966.501		
Eng Main LOX Vlv Cls - On		K0633	966.521		
Eng LOX Turb Byp Vlv Cls - Off		K0463	966.603	K0125	966.608

TABLE 5-1 (Sheet 15 of 20)
SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng M/S OK Press Sw No. 2 - Off				K0157	966.542
Eng Main LH_2 Vlv Cls - On		K0632	966.640		
Fwd Bus Transfer External Indication - Off		K0639	966.637		
Aft Bus 1 Transfer External Indication		K0622	966.786		
Eng LOX Turb Byp Vlv Opn		K0461	967.116	K0124	967.192
Aft Bus 2 Transfer External Indication		K0623	966.959		
Eng Cont He Sol Vlv Ener - Off		K0531	967.303	K0007	967.306
Eng Cutoff Lockin Ind - Off		K0539	967.305	K0013	967.350
Eng Ready Sig - On		K0530	967.308	K0012	967.350
Eng Pmp Prg Cont Vlv Enable On	24	K3890	966.531		
LH_2 & LOX Prevalve Closed Command - On	GSE	K3867	967.628		
LH_2 & LOX Prevalve Closed Ener		K0576	967.62[illegible]		
LH_2 Prevlv Open Indication - Off		K0540	967.740	K0111	967.758
LOX Prevlv Open Indication - Off		K0541	967.751	K0109	967.758
LH_2 Prevlv Cls - On		K0549	968.060	K0112	968.092
LOX Prevalve Close - On		K0550	968.099	K0110	968.092

TABLE 5-1 (Sheet 16 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
S-IVB Engine Start Off	27	K3890	968.240		
Cold He Sov Cls Cmd - On	GSE	K3802	968.313		
Cold He Sov Opn Ener - Off		K0571	968.319		
S-IVB Engine Cutoff	12	K3890	968.365		
Engine Cutoff Ind - Sw Sel - On		K0418	968.369	K0140	*966.317
LOX Tk Press Shutoff Vlvs Cls On	79	K3890	968.456		
First Burn Relay Off	69	K3890	968.563		
Second Burn Relay Off	33	K3890	968.654		
LOX Tank Flight Press System Off	104	K3890	968.744		
LOX Chilldown Pump Off	23	K3890	968.892		
LH_2 Chilldown Pump Off	59	K3890	968.983		
Point Level Sensor Disarming	98	K3890	970.357		
Fuel Inj Temp OK Bypass Reset	16	K3890	971.606		
Ullage Chg Reset	88	K3890	971.971		
Ullage Firing Reset	73	K3890	972.086		
T/M Calibration Off	63	K3890	972.176		
Heat Exchanger Bypass Valve Enab On	50	K3890	972.448		
LOX Cold He Dump Cmd - On	GSE	K3843	972.549		

*This event was turned on by the GSE initiated cutoff.

TABLE 5-1 (Sheet 17 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng Cont Btl Dmp Opn - On	GSE	K3817	972.574		
PU Boiloff Bias Cutoff - On	34	K3890	972.782		
PU LH_2 Boiloff Bias On Ind - On		K0417	972.787		
PU Boiloff Bias Cutoff Off	35	K3890	987.814		
PU LH_2 Boiloff Bias Cutoff On Ind - Off		K0417	987.818		
Aux Hyd Pmp Flt Mode Off	29	K3890	987.930		
Aux Hyd Pmp Flt Rel Rst		K0621	987.934		
Aux Hyd Pmp On Ener No		K0513	988.182		
PU Mixture Ratio 4.5 On	17	K3890	1,658.870		
PU Open Loop Rels Rst - Off		K2440	1,658.876		
PU Programmed Mixture Ratio Off	18	K3890	1,661.008		
PU Opn Loop Rels Rst - On		K2440	1,661.016		
Eng Lkt C/T Pwr Cmd - Off	GSE	K4796	1,661.137		
Eng Lkt GSE Pwr Cmd - Off	GSE	K4797	1,661.164		
Comp Test Lkt Ind - Off	GSE	K3805	1,681.961		
Non Prog Veh Eng Cutoff Ind - Off		K0419	1,681.964		
S-IVB Eng Cutoff Off	13	K3890	1,688.094		
Eng Cutoff Ind - Sw Sel - Off		K0418	1,688.100		
Eng Ctf - Ind Off		K0522	1,688.103		

TABLE 5-1 (Sheet 18 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 & LOX Prevlv - Cls Cmd - Off	GSE	K3867	1,688.233		
LH_2 & LOX Prevlv Cls Ener - Off		K05[illegible]0	1,688.236		
LOX Prevlv - Cls Ind - Off		K0550	1,688.991		
LH_2 Prevlv - Cls Ind - Off		K0549	1,689.124		
LOX Prevlv Open Ind - On		K0541	1,690.434		
LH_2 Prevlv Open Ind - On		K0540	1,690.591		
LH_2 & LOX C/D SOV Cls Cmd - Off	GSE	K3862	1,688.258		
LH_2 & LOX C/D SOV Cls Ener - Off		K0577	1,688.261		
LH_2 C/D SOV Cls Ind - Off		K0551	1,689.290		
LOX C/D SOV Cls Ind - Off		K0552	1,689.368		
LOX C/D SOV Opn Ind - On		K0545	1,689.782		
LH_2 C/D SOV Opn Ind - On		K0544	1,690.011		
S-IVB Eng Cutoff - Off	13	K3890	1,695.6[illegible]9		
LOX Tk Press Shutoff Vlvs Cls - Off	80	K3890	1,695.825		
LOX Tk Press Shutoff Vlvs Rst Ind - On		K0416	1,695.829		
LH_2 Tk Vnt Dir Flt Pos - Off	GSE	K0562	1,696.180		
LH_2 Tk Vnt Dir Gnd Pos - On	GSE	K0561	1,696.243		
T/M Prelaunch C/O Grp Pwr On Cmd - On	GSE	K0406	1,787.139		
T/M Prelaunch C/O Grp On Ind - On		K0408	1,787.190		

TABLE 5-1 (Sheet 19 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
T/M Prelaunch C/O Grp Pwr On Cmd - Off	GSE	K0406	1,787.324		
T/M Cal. On	62	K3890	1,787.499		
T/M Cal. Off	63	K3890	1,688.610		
End of Cals	GSE	K4802	1,813.446		
Prl Co Grp Pwr Off Cmd - On	GSE	K0403	1,814.042		
Prl Co Grp Pwr On - Ind - Off	GSE	K0408	1,814.080		
Prl Co Grp Pwr Off Cmd - Off	GSE	K0403	1,818.371		
T/M RF Grp Xfer Grd Mon Cmd - On	GSE	K0420	1,818.374		
Prl Co Grp Pwr On Cmd - On	GSE	K0406	1,868.208		
Prl Co Grp Pwr On Ind - On		K0408	1,868.260		
Prl Co Grp Pwr On Cmd - Off	GSE	K0406	1,868.394		
T/M Cal. On	62	K3890	1,868.569		
T/M Cal. Off	63	K3890	1,869.682		
End of Cals	GSE	K4802	1,894.520		
Prl Co Group Pwr Off Cmd - On	GSE	K0408	1,895.122		
Prl Co Group Pwr On Ind - Off		K0408	1,895.159		
T/M RF Group Xfer Grd Mon Cmd - Off	GSE	K0420	1,919.861		
Prl Co Group Pwr Off Cmd - Off	GSE	K0403	1,919.861		

TABLE 5-1 (Sheet 20 of 20)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	GSE/ SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng Cont Bus Pwr Off Cmd - On	GSE	K3815	1,943.285		
Eng Cont Bus Pwr Ind - Off		K0628	1,943.223		
Eng Cont Bus Pwr Off Cmd - Off	GSE	K3815	1,943.583		
Eng Ign Bus Pwr Off Cmd - On	GSE	K3818	1,943.585		
Eng Ign Bus Pwr - Ind Off		K0630	1,943.624		
Eng Ign Bus Pwr Off Cmd - Off	GSE	K3818	1,943.902		

TABLE 5-2 (Sheet 1 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Burner Start (T_A)*					
T/M Calibration On	62	K3890	-353.831		
T/M Calibration Off	63	K3890	-352.717		
End of CALS	GSE	K4802	-340.323		
T/M Prelaunch C/O Group Pwr Off Cmd - On	GSE	K0403	-327.284		
T/M Prelaunch C/O Group On Ind - Off		K0408	-327.244		
T/M Prelaunch C/O Group Pwr Off Cmd - Off	GSE	K0403	-318.488		
Aft Bus 1 Transfer Internal Indication - On	GSE	K0622	-318.448		
Aft Bus 2 Transfer Internal Indication - On	GSE	K0623	-318.189		
Fwd Bus Pwr Transfer Internal Indication - On		K0639	-317.940		
Ambient Repress Mode Sel Off and Cryo On	37	K3890	-313.286		
Burner LH2 Prop Vlv Close Off	61	K3890	-313.195		
Burner LOX Shutdown Valve Close Off	75	K3890	-313.105		
Burner Automatic Cutoff System	85	K3890	-308.492		
O_2-H_2 Brnr Voting Ckt Enab Ind - On		K0438	-308.489		

*T_A = 1134:54.000

TABLE 5-2 (Sheet 2 of 1[illegible])
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
O_2-H_2 BRNR GH_2 Inlet Lo Temp Simu 1 Cmd - On	GSE	K5828	-308.279		
O_2-H_2 Brnr GH_2 Inlet Lo Temp Simu 2 Cmd - On	GSE	K5829	-308.252		
O_2-H_2 Brnr GH_2 Inlet Lo Temp Ind - On		K0464	-308.2[illegible]		
LH_2 & LOX Repress Amb Mode - On		K0440	-308.219	K0195	-308.194
Amb Repress Mode Sel Off and Cryo On	37	K3890	[illegible]03.133		
LH2 & LOX Repress Amb Mode - Off		K0440	-303.130	K0195	-303.027
Burner Voting Circuit Enable Off	86	K3890	-303.855		
O_2-H_2 Brnr Voting Ckt Enab Ind - Off		K0438	-303.848		
Burner LH_2 Prop Valve Close Off	61	K3890	-303.7[illegible]1		
Burner LOX Shutdown Valve Close Off	75	K3890	303.610		
LOX Tank NPV Valve Latch Open On	44	K3890	-302.556		
Burner LH_2 Prop Valve Open On	26	K3890	-000.670		
Burner LH_2 Prop Valve Close - Off		K0432	-0.611	K0180	-0.555
Burner LH_2 Prop Valve Open - On		K0431	-0.577	K0181	-0.555

TABLE 5-2 (Sheet 3 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Burner Exciters On	70	K3890	-0.363		
Burner LOX Shutdown Valve Open On	89	K3890	0.061		
Burner LOX Shutdown Valve Close - Off		K0428	0.132		
Burner LOX Shutdown Valve Open - On		K0427	0.140	K0192	0.220
LH_2 Tank Cont Vent Valve Close On	84	K3890	0.269		
LH_2 Tank Cont Vent Valve Relays Reset - Off		K0452	0.275		
LH_2 Tank Cont Vent Relief Override Valve Closed - On		K0699	0.296	K0154	0.354
LH_2 Tank Cont Vent Orf Bypass Valve Open - Off		K0451	0.392		
LH_2 Tank Cont Vent Orf Bypass Valve Closed - On		K2400	0.399	K0155	0.453
Burner LH_2 Prop Valve Open Off	72	K3890	0.876		
Burner LOX Shutdown Valve Open Off	90	K3890	1.583		
LH_2 Tank Cont Vent Valve Close Off	87	K3890	2.290		
LH_2 Tank Cont Vent Valve Relays Reset - On		K0452	2.299		
Burner Exciters Off	71	K3890	3.454		

TABLE 5-2 (Sheet 4 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Burner Voting Circuit Enable On	85	K3890	6.159		
Burner Automatic Cutoff Sys Enable On		K0438	6.164		
LH_2 Tank Repress Control Valve Open On	39	K3890	6.271		
LH_2 Repress Valve Ener - On		K0443	6.281		
LOX Tank Repress Cont Valve Open On	3	K3890	6.479		
LOX Tank Repress Valve Ener On		K0444	6.493		
LOX Tank Repress Cont Valve Open Off	4	K3890	176.875		
LOX Tank Repress Valve Ener Off		K0444	176.888		
Aux Hyd Pump Flt Mode - On	28	K3890	177.576		
Aux Hyd Pump Flt Rel Rst - Off		K0621	177.580		
Aux Hyd Pump On - Ener		K0513	177.665		
LOX Tank Repress Cont Valve Open Off	4	K3890	207.008		
LOX Chilldown Pump On	22	K3890	207.166		
LOX Chilldown Pump Rel Rst - Off		K0644	207.172		
LOX Chilldown Pump Inv On		K0519	207.174		

TABLE 5-2 (Sheet 5 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Chilldown Pump On	58	K3890	212.221		
LH_2 Chilldown Pump Rel Rst Off		K0641	212.227		
LH_2 Chilldown Pump Inv On		K0512	212.230		
LH_2 and LOX Prevalve Close Command - On	GSE	K3867	217.407		
LH_2 Prevalve Open Indication - Off		K0540	217.523	K0111	217.608
LOX Prevalve Open Indication - Off		K0541	217.529	K0109	217.608
LH_2 Prevalve Closed Indication - On		K0549	217.875	K0112	217.858
LOX Prevalve Closed Indication - On		K0550	217.888	K0110	217.942
Second Burn Relay Cn	32	K3890	408.143		
LH_2 Tank Flt Press Valve Ener - On		K0524	408.152		
LH_2 Tank Step Pres Vlv Ener		K0523	408.152		
PU Mixture Ratio 4.5 On	17	K3890	408.233		
S-IVB Ull Engine No. 1 On	42	K3890	454.266		
S-IVB Ull Engine Rel Rst		K0429	454.274		
S-IVB Ull Engine No. 2 On	101	K3890	454.356		
LOX Tank Repress Cont Vlv Oper Off	4	K3890	454.494		

TABLE 5-2 (Sheet 6 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Tank Repress Cont Vlv Open Off	81	K3890	454.633		
Burner LH_2 Prop Valve Closed On	60	K3890	454.777		
Burner LH_2 Prop Valve Close - On		K0432	454.859	K0180	454.903
Burner LH_2 Prop Valve Open - Off		K0431	454.833	K0181	454.903
Burner Voting Circuit Enable Off	86	K3890	454.981		
Burner Voting Circuit Enable - Off		K0438	454.986		
LH_2 Tank Cont Vent Valve Close On	84	K3890	455.194		
LH_2 Tank Cont Vent Valve Relays Reset - Off		K0452	455.201		
Amb Repress Mode Sel On	36	K3890	455.597		
LH_2 + LOX Repress Mode Amb - On		K0440	455.600	K0195	455.653
LH_2 Tank Cont Vent Valve Close Off	87	K3890	457.221		
LH_2 Tank Cont Vent Valve Relays Reset - On		K0452	457.229		
Burner LH_2 Prop Valve Close Off	61	K3890	457.826		

TABLE 5-2 (Sheet 7 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Burner LOX Shutdown Valve Close On	74	K3890	459.345		
Burner LOX Shutdown Valve Close - On		K0428	459.411		
Burner LOX Shutdown Open - Off		K0427	459.413	K0192	459.428
LH_2 Tank Cont Vent Valve Close Off	87	K3890	459.484		
Burner LOX Shutdown Valve Close Off	75	K3890	462.418		
LH_2 & LOX Prevalves Close Cmd - Off (Open)	GSE	K3867	517.417		
LH_2 + LOX Prevlv Close Ener - Off		K0576	517.418		
LOX Prevalve Clsd Off		K0550	518.157	K0110	518.164
LH_2 Prevalve Clsd Off		K0549	518.313	K0112	518.330
LOX Prevalves Open - On		K0541	519.577	K0109	519.580
LH_2 Prevalves Open - On		K0540	519.712	K0111	519.747
LH_2 Chilldown Pump Off	59	K3890	527.487		
LH_2 C/D Pmp Inv Off - Indication		K0512	527.492		
LH_2 C/D Pmp Relay Rst Indication - On		K0641	527.494		
LOX Chilldown Pump Off	23	K3890	527.695		
LOX C/D Pmp Inv Indication - Off		K0519	527.701		

TABLE 5-2 (Sheet 8 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX C/D Pmp Relay Rst Indication		K0644	527.702		
Aux Hyd Pump Flt Mode Off	29	K3890	528.944		
Aux Hyd Pump Flt Rel Rst - Off		K0621	528.948		
S-IVB Ull Engine No. 1 Off	43	K3890	529.088		
S-IVB Ull Engine No. 2 Off	102	K3890	529.189		
S-IVB Ull Engine Rel Rst		K0429	529.198		
PU Program Mixture Ratio Off	18	K3890	529.303		
LH_2 Tank Cont Vent Orf Bypass Valve Open On	111	K3890	548.293		
LH_2 Tank Cont Vent Valve Relays Reset - Off		K0452	548.301		
LH_2 Tank Cont Vent Orf Bypass Valve Closed - Off		K2400	548.451	K0155	548.486
LH_2 Cont Vent Orf Bypass Valve Open - On		K0451	548.443		
LH_2 Tank Cont Vent Relief Override Valve Open On	107	K3890	543.383		
LH_2 Tank Cont Vent Relief Override Valve Closed - Off		K0699	548.403	K0154	548.469
LH_2 Tank Cont Vent Orf Bypass Valve Open Off	112	K3890	550.498		

TABLE 5-2 (Sheet 9 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Tank Cont Vent Relief Override Valve Open Off	108	K3890	550.588		
LH_2 Tank Cont Vent Valve Relays Reset -		K0452	550.597		
LOX Tank Repress Cont Valve Open On	3	K3890	719.743		
LOX Tank Repress Valve Ener -		K0444	719.755		
LH_2 Tank Cont Vent Valves Close On	84	K3890	724.277		
LH_2 Tank Cont Vent Valve Relays Reset - Off		K0452	724.284		
LH_2 Tank Cont Vent Relief Override Closed - On		K0699	724.305	K0154	724.370
LH_2 Tank Cont Vent Orf Bypass Open - Off		K0451	724.396		
LH_2 Tank Cont Vent Orf Bypass Valve Closed - On		K2400	724.318	K0155	724.470
LH_2 Tank Cont Vent Valve Close Off	87	K3890	726.413		
LH_2 Tank Cont Vent Valve Rst - On		K0452	726.421		
LH_2 Tank Repress Cont Valve Open On	39	K3890	740.237		
LH_2 Tank Repress Vlv Ener		K0443	740.245		
LH_2 Tank Repress Vlv Ener		K0443	771.865		
LH_2 Tank Step Pres Vlv Ener		K0523	771.866		

TABLE 5-2 (Sheet 10 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Tank Repress Cont Valve Open Off	81	K3890	824.508		
LOX Tank Repress Cont Valve Open - Off	4	K3890	824.608		
LH_2 Latch Relay Valve Opn Latch Cmd - Off	GSE	K5842	826.736		
LH_2 Latch Relief Valve Open Latch Off	19	K3890	826.807		
LH_2 Latch Relief Valve Open - On	99	K3890	828.962		
LH_2 Latch Relief Valve Closed Ind - Off		K2431	829.040	K0210	829.036
LH_2 Latch Relief Valve Open Ind - On		K2429	829.047	K0211	829.119
LH_2 Latch Relief Valve Open Latch On	52	K3890	829.156		
LH_2 Vents Bst Cls and Latch Relays Reset Ind-Off		K2430	829.163		
LH_2 Latch Relief Valve Open - Off	100	K3890	829.827		
LH_2 Latch Relief Valve Open Ind - Off		K2429	830.041	K0211	830.119
LH_2 Latch Relief Valve Open Latch Off	19	K3890	830.940		
LH_2 Vents Bst Cls and Latch Relays Reset Ind - On		K2430	830.948		

TABLE 5-2 (Sheet 11 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Latch Relief Valve Open On	99	K3890	868.604		
LH_2 Latch Relief Valve Open Ind - On		K2429	868.676	K0211	868.698
LH_2 Latch Relief Valve Open Off	100	K3890	868.916		
LH_2 Latch Relief Valve Open Ind - Off		K2429	869.119	K0211	869.198
LH_2 Latch Relief Valve Closed - On		K2431	869.246	K0210	869.282
LH_2 Latch Relief Valve Open Latch Cmd - On		K5842	869.270		
LH_2 Tank Vent Valve Cmd - On	GSE	K3839	869.352		
LH_2 Tank Vent Valve Open Ener - On		K0516	869.352		
LH_2 Tank Vent Valve Close Ind - Off		K0532	869.415	K0001	869.457
LH_2 Tank Vent Valve Open Ind - On		K0542	869.464	K0017	869.457
LOX NPV Valve Open Latch Off	45	K3890	873.760		
LOX Vents Bst Cls and Latch Relays Reset Ind On		K2424	873.769		
LOX NPV Valve Open On	105	K3890	875.923		
LOX NPV Valve Closed Ind - Off		K0446	876.014	K0199	876.023
LOX NPV Valve Open Ind - On		K0465	876.021	K0198	876.097

TABLE 5-2 (Sheet 12 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX NPV Valve Open Latch On	44	K3890	876.103		
LOX Vents Bst Cls and Latch Relays Reset Ind-Off		K2424	876.109		
LOX NPV Valve Open Off	106	K3890	876.741		
LOX NPV Valve Open Ind-Off		K0465	876.995	K0198	877.014
LOX NPV Valve Open Latch Off	45	K3890	877.876		
LOX Vents Bst Cls and Latch Relays Reset Ind - On		K2424	877.885		
LOX NPV Valve Open On	105	K3890	967.508		
LOX NPV Valve Open Ind - On		K0465	967.589	K0198	967.589
LOX NPV Valve Open Off	106	K3890	967.869		
LOX NPV Valve Open Ind-Off		K0465	968.111	K0198	968.173
LOX NPV Valve Closed Ind - On		K0446	968.279	K0199	968.265
LOX NPV Valve Open Latch On	44	K3890	968.387		
LOX Vents Bst Cls and Latch Relays Reset Ind - Off		K2424	968.394		
LOX Tank Vent Valve Cmd - On	GSE	K3853	968.499		
LOX Tank Vent Valve Open Ener - On		K0575	968.500		
LOX Tank Vent Valve Closed Ind - Off		K0533	968.546	K0002	968.62[illegible]
LOX Tank Vent Valve Open Ind - On		K0543	968.574	K0016	968.514

TABLE 5-2 (Sheet 13 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Fwd Bus Pwr Int Ind - Off	GSE	K0639	971.814		
Aft Bus 1 Transfer Int Ind - Off	GSE	K0622	972.066		
Aft Bus 2 Transfer Int Ind - Off	GSE	K0623	972.338		
T/M Prelaunch C/O Grp Pwr On Cmd - On	GSE	K0406	976.359		
T/M Prelaunch C/O Grp Pwr On Ind - On		K0408	976.413		
T/M Prelaunch C/O Grp Pwr On Cmd - Off	GSE	K0406	976.532		
T/M Cals On	62	K3890	976.708		
T/M Cals Off	63	K3890	977.822		
End of Cals	GSE	K4802	1002.659		
T/M Prelaunch C/O Grp Pwr Off Cmd - On	GSE	K0403	1003.256		
T/M Prelaunch C/O Grp Pwr On Ind - Off		K0408	1003 293		
T/M Prelaunch C/O Grp Pwr Off Cmd - Off	GSE	K0403	1013.207		
PU Mixture Ratio 4.5 On	17	K3890	1013.246		
PU Open Loop Relays Reset - Off		K2440	1013.253		
PU Programmed Mixture Ratio Off	18	K3890	1023.395		
PU Open Loop Releys Reset - On		K2440	1023.403		

TABLE 5-2 (Sheet 14 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
PU Mixture Ratio 5.5 On	66	K3890	1023.614		
PU Open Loop Relays Reset - Off		K2440	1023.621		
PU Programmed Mixture Ratio Off	18	K3890	1033.728		
PU Open Loop Relays Reset - On		K2440	1033.737		
Eng Control Bus Pwr Off Cmd - On	GSE	K3815	1033.857		
Eng Control Bus Pwr Ind - Off		K0628	1033.894		
Eng Control Bus Pwr Off Cmd - Off	GSE	K3815	1034.005		
Eng Ignition Bus Pwr Off Cmd - On	GSE	K3818	1034.007		
Eng Ignition Bus Pwr Ind - Off		K0630	1034.046		
Eng Ignition Bus Pwr Off Cmd - Off	GSE	K3815	1034.328		
Engine Cutoff Off	13	K3890	1034.366		
Eng Cutoff Ind Swsel - Off		K0418	1034.372		
Eng Cutoff Ind - Off		K0522	1034.376		
LOX Press Heat Exchng Bypass Vlv Enab On	50	K3890	1336.062		
Eng Pump Purge Control Vlv Enable Off	25	K3890	1336.658		

TABLE 5-2 (Sheet 15 of 15)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL OR GSE	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
PU Programmed Mixture Ratio Off	18	K3890	1336.779		
LH_2 First Burn Rel Off	69	K3890	1336.889		
LH_2 Second Burn Off	33	K3890	1337.005		
LH_2 Vent and Latch Relief Vlvs Bst Cls Off	78	K3890	1337.129		
LOX Vent and NPV Vlvs Bst Cls Off	96	K3890	1337.261		
T/M Cal. Off	63	K3890	1337.378		
PT Level Sensors Arm Off	98	K3890	1337.490		
PU Boiloff Bias Cutoff Off	35	K3890	1337.656		

6. ENGINE SYSTEM

The S-IVB-509 stage acceptance firing was performed with an uprated (230,000 lbf thrust) Rocketdyne engine S/N 2124 (figure 6-1) mounted on the stage. The engine was manufactured in the configuration baseline designed for J-2 engine S/N 2088 and subs and described in the Rocketdyne configuration report (R-5788). The manufacturer conducted the engine acceptance test program on 18, 19, and 21 September 1967. The necessary performance demonstration was achieved in three test firings with an accumulated duration of 349.8 sec. As a result of these tests the engine performance tag values were established as follows:

Thrust (F)	227.020 lbf
Engine mixture ratio (EMR)	5.509
Specific impulse (Isp)	424.0 sec

The tag values were established with a LOX flowmeter constant of 5.6240 cycles per gallon (cpg) and an LH_2 flowmeter constant of 1.8797 cpg. The gas generator feed system contained orifices with diameters of 0.276 in. for LOX and 0.485 in. for LH_2. The engine was equipped with a 1-sec start tank discharge valve timer in the engine control. None of the other modifications significantly affected performance.

6.1 Engine Chilldown and Conditioning

6.1.1 Turbopump Chilldown

Chilldown of the engine LOX and LH_2 turbopumps was adequate to provide the conditions required for proper engine start. An analysis of the chilldown operation is presented in paragraphs 7.4 and 8.3.

6.1.2 Thrust Chamber Childown

The thrust chamber skin temperature (figure 6-2) was 236 degrees R at engine start command, well within the engine start requirements of 235 ±75 degrees R. The rate of chilldown was normal, and the terminal temperatures were comparable to those on previous acceptance tests (table 6-1) except S-IVB-508 which had an abnormally slow chill. The LH_2 pump start transient buildup characteristics were satisfactory, as shown in figure 6-3.

6.1.3 Engine Start Sphere Chilldown and Loading

Chilldown and loading of the GH_2 start sphere (figure 6-4) met requirements for engine start (figure 6-5). The warmup rate averaged 2.0 degrees R/min from sphere pressurization to engine start command. Significant data from three S-IVB stages are compared in table 6-2.

6.1.4 Start Tank Refill Performance

Figure 6-6 shows the refill performance of the J-2 engine start tank during the S-IVB-509 stage acceptance firing. Immediately prior to start tank discharge, the start tank conditions (1351 psia and 269 deg R) were within the safe start envelope. When the start tank discharge valve (STDV) opened, the GH_2 discharged through the turbines as shown in figure 6-6. The discharge was completed and the refill initiated when the temperature and pressure were 176 deg R and 142 psia, respectively, at ESC +1.50 sec. Except for the initial period when the injector was at its lowest temperature (immediately after fuel lead) the refill was practically an exact reversal of the discharge. The tank was topped with lower temperature hydrogen from the LH_2 pump discharge starting at ESC +7.64 sec. The topping was terminated when start tank temperature reversal occurred at the initiation of heatup. At this time (ESC +44.643 sec) the tank pressure and temperature were 1,156 psia and 201.9 deg R, respectively. Environmental heating caused the start tank pressure and temperature to increase to the required level for start.

Figure 6-7 shows the restart capability of the engine based on a Rocketdyne-determined criterion. The start tank pressure at STDV +60 sec (ESC +61.134 sec) was 1,185.0 psia as compared to a minimum allowable of 950 psia. At ESC +76.143 sec, the start tank conditions was within the safe start envelope; at engine cutoff command, the pressure and temperature were 1,357.1 psia and 241.7 deg R. The pressure reached the relief valve setting (1,357 psia) during the firing.

6.1.5 Engine Control Sphere Chilldown and Loading

The engine control sphere conditioning was adequate (figure 6-8), and all objectives were satisfactorily accomplished. Significant engine control sphere performance data from four S-IVB stages are compared in table 6-3.

6.2 J-2 Engine Performance Analysis Methods and Instrumentation

Engine performance for the acceptance firing was calculated by use of computer program PA63. The average performance during given intervals was calculated by computer program PA49. Computer program PA53, utilizing revised techniques and the latest Rocketdyne correlations, was used to compute start and cutoff transient performance. Computer program G105-1 was used to determine propellant consumption during burn; program UT23 was also used to analyze and study engine component performance. A description of the operation and a comparison of the results of these programs is presented in table 6-4. Data inputs to the computer programs, with the applicable biases, are shown in table 6-5.

6.3 J-2 Engine Performance

The engine performance was satisfactory. Plots of selected data showing engine characteristics are presented in figures 6-9 through 6-13. The engine propellant inlet conditions are discussed in sections 7 and 8.

The 509 acceptance test demonstrated both closed loop and open loop operation. At ESC +350 sec, the PU system was deactivated and the PU valve was commanded to the full open (4.5/1.0 EMR) position. At ESC +410 sec, this command was removed and the valve went to the null position for the remainder of the firing. This test also provided engine performance data at 5.5/1.0, 5.0/1.0, and 4.5/1.0 mixture ratios for use in flight prediction. Cutoff was initiated by the fuel depletion sensors. All engine performance parameters indicated nominal engine performance immediately prior to and during engine cutoff.

The engine tag performance level at ESC +60 sec as determined by computer program PA63 (Past-641 deck) was as follows:

Parameter	DAC Acceptance	Rocketdyne Acceptance	Difference	Run to Run
Thrust (lbf)	224,665	226,214	-1,549	±2,216
Mixture ratio	5.494	5.521	-0.027	±0.03
Specific impulse (sec)	424.2	424.2	0.0	±2.46

These values are comparable, within the run-to-run deviations, to the J-2 engine acceptance results. The composite values for steady-state performance are shown in table 6-6.

Flow integral mass analysis indicated that 187,383 lbm of LOX and 36,866 lbm of LH_2 were consumed between engine start command and engine cutoff command. The overall stage average performance from the 90 percent performance level (ESC +3.630 sec) to engine cutoff (ESC +455.335 sec) is presented in table 6-6. The variation of specific impulse with mixture ratio is shown in figure 6-14.

The total impulse generated from engine start command to engine cutoff command (fuel depletion) was 95.53×10^6 lb sec. This was only slightly less than the predicted total impulse of 96.43×10^6 lb sec. The 0.93 percent deviation is within the prediction accuracy of one percent. The 4.113 sec difference between the actual (ESC +455.335 sec) and predicted (ESC +459.448 sec) depletion times is also within the prediction accuracy.

6.3.1 Start Transient

The J-2 engine start transient was satisfactory. A summary of engine performance is presented in the following table:

Parameter	Acceptance Firing	Log Book
Time to 90 percent performance level (seconds)	ESC +3.630	ESC +3.500
Time of start tank discharge command (seconds)	ESC +1.130	ESC +1.000
Thrust at 90 percent performance level (lbf)	167,826	187,667
Total impulse (lbf-sec)	149,808	175,014*

*Based on stabilized thrust at null PU and standard altitude conditions

Thrust buildup to the 90 percent performance level (STDV +2.5 seconds) was within the maximum and minimum thrust bands as shown in figure 6-15. The acceptance firing total impulse was 25,206 lbf-sec lower than the value given in the log book. This was due to a slow thrust rise rate during the second stage travel of the main oxidizer valve. This slow rise rate was also evident on the S-IVB-508 acceptance firing.

6.3.2 Steady State Performance

The J-2 engine performed satisfactorily during the steady-state portion of engine burn. During closed PU valve operation, performance deviation was less than 0.7 percent. Overall deviations were a result of the difference in predicted and actual cutback times (refer to section 11) and the difference in predicted and actual engine responses after cutback. Average performance values for the acceptance firing steady-state operation are presented in figure 6-16 and compared with predicted performance values in table 6-6.

Engine thrust variations during the acceptance firing are presented in table 6-7. They are compared to the predicted acceptance firing thrust history and to Contract End Item (CEI) thrust variation limits for flight. These limits do not apply to acceptance firing performance and are presented for reference only. The thrust variations will be modified by flight effects on stage operation. Thrust variations during four periods of engine operation are presented in figure 6-17 and discussed in the following paragraphs:

a. The thrust variations during hardover, or maximum engine mixture ratio operation (EMR = 5.5) were within the CEI limits for normal engine operation. (Engine performance shifts are excluded from CEI specifications.) Normal operating thrust variations during this period of engine burn are caused by stabilization of the engine and by stage perturbations, including the effects of variations in propellant supply environmental conditions.

b. Thrust variations during the transient period from closed loop PU valve cutback +75 seconds to open loop PU valve cutback were within the CEI limits for normal engine operation. The thrust variations during this period were caused by stabilization of the engine after cutback and can be directly linked to movements of the PU valve. Data derived from the acceptance firing will aid in the flight calibration of the PU system in order to more accurately predict the thrust variation during this cutback transient.

c. Thrust variations were also examined during the periods of 4.5/1.0 EMR and 5.0/1.0 EMR open loop operation. Since the PU valve was in a fixed position during these intervals, the thrust variations during these times were compared to the required limits during full closed PU valve operation. These variations were also within CEI limits.

6.3.3 Cutoff Transient

The time lapse between engine cutoff, as received at the J-2 engine, and thrust decrease to 11,500 lbf was within the maximum allowable time of 800 ms for the acceptance firing as shown in the following table:

Parameter	Acceptance Firing	Log Book
Time of thrust decrease to 11,500 lbf (ms)	541	348
Measured total impulse (lbf-sec)	37,539*	31,763
Total impulse corrected to null (-2.0 deg) PU valve position (lbf-sec)	38,476	31,763
Total impulse corrected to 0 deg F oxidizer valve skin temperature (lbf-sec)	**	32,988

*PU valve at -0.76 deg
**Valve skin temperature data not available

The thrust decay time for the acceptance firing was greater than the log book value, and the cutoff total impulse was correspondingly higher than the log book value. For this firing, the total impulse was corrected to null PU valve position so that a direct comparison would be made to the log book value. It was not possible to accurately correct to 0 deg F LOX valve skin temperature since the measurement was not available; however, this correction would be approximately -4,500 lb-sec for an acceptance test since the MOV temperature should be about 355 deg R. Based on this assumption, the corrected total impulse would be within 988 lbf-sec of the log book value. Figure 6-18 presents the data for the thrust chamber pressure cutoff transient, the accumulated cutoff impulse, and the cutoff thrust to the 11,500 lbf level.

6.4 Engine Sequencing

The engine sequencing was satisfactory throughout the acceptance firing and compatible with the engine logic and the acceptance firing test plan. However, as in past acceptance tests, the sequence times differ in many respects from the values quoted in the log book.

Most of the disagreements between measured and log book values are insignificant and may be ascribed to sampling rate errors or to the effects of the liquids that are present during the acceptance firing but absent during log book testing. Almost all event times were obtained from the hardwire because the sampling rate was better than for TM.

Figure 6-19 presents the engine start sequence for the acceptance firing; table 6-8 presents the time of significant events during the firing and compares them with the nominal values.

6.5 Component Operation

6.5.1 Main LOX Valve

The main LOX valve opened satisfactorily during the acceptance firing. The opening time data are as follows:

Item	Specification	Acceptance Firing
First stage travel (ms)	50 ±25	46
First plateau (ms)	510 ±70	547
Second stage travel (ms)	1,825 ±75	1,788
Total time (ms)	2,385 ±170	2,381

The above valve opening times were within specifications for the acceptance test. The valve closing time was 150 ms which was approximately 15 ms longer than the maximum specified; however, this did not contribute to any significant reduction in cutoff transient performance.

6.5.2 PU Valve

At engine start command, the PU valve was at -1.60 deg (null) which was within the -2 ±2 deg limit. PU activation occurred at ESC +6.166 sec.

The PU valve went to the high EMR position where it remained until PU cutback at ESC +196 sec as shown in figure 6-13. The engine mixture ratio (EMR) was properly controlled to the required reference of 5.0/1.0 following cutback.

Also the PU valve went to the full open position when commanded to do so during the open loop portion of the test. When the full open command was removed the valve returned to near null position.

6.5.3 LH_2 Pump

Pump performance was normal throughout the test. The stall margin as indicated by the characteristic head versus flow curve in figure 6-3 was normal. The pump also performed satisfactorily during mainstage and responded characteristically to PU system cutback and excursions. Mainstage pressure and speed data are presented in figure 6-10.

6.5.4 LOX Pump

LOX pump performance was satisfactory. LOX pump speed and discharge pressure and temperature responded to PU system cutback and excursions and also to engine inlet conditions. The pressure and temperature increases across the pump were satisfactory. Performance profiles indicative of the pump operation are shown in figure 6-10.

6.5.5 Turbines

Performance of both LH_2 and LOX turbines was satisfactory. Temperatures and pressures for both turbines responded as expected to PU system cutback and excursions. The LH_2 turbine inlet temperature (C0001) was in error during burn and had to be calculated from the LOX turbine inlet temperature (C0002). Pressure and temperature drops across the turbines were nominal. Performance profiles are presented in figure 6-10.

6.5.6 Gas Generator

The gas generator (GG) performance was adequate. The GG chamber pressure and LH_2 turbine inlet temperature indicated nominal values before and after EMR cutback. Plots of GG performance are shown in figures 6-10 and 6-20.

6.5.7 Engine Driven Hydraulic Pump

The engine driven hydraulic pump performed satisfactorily during the acceptance firing. The required horsepower at 60 sec after engine start was 5.36.

TABLE 6-1

THRUST CHAMBER CHILLDOWN DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507	S-IVB-506N
Thrust chamber chilldown initiated (sec from simulated liftoff)	-408.595	-407.938	-407.942	-408.537
Thrust chamber chilldown terminated (sec from simulated liftoff)	488.042	488.793	488.808	488.474
Thrust chamber temperature				
Required at engine start command (deg R)	235 ±75	235 ±75	235 ±75	235 ±75
At engine start command (deg R)	236	267	221	237
At end of chilldown (deg R)	231	255	213	228

TABLE 6-2

ENGINE START SPHERE PERFORMANCE DATA

Parameter	Temperature (°R)			Pressure (psia)			Mass (lbm)		
	509	508	507	509	508	507	509	508	507
Engine start requirement	See start region Figure 6-5			See start region Figure 6-5			--	--	--
Engine start command							3.79	3.53	3.50
After start sphere blowdown	176	196	188	142	157	185	0.64	0.63	0.77
Engine cutoff command	242	246	233	1,357	1,354	1,329	4.19	4.09	4.22
Total GH2 usage during start	--	--	--	--	--	--	3.15	2.90	2.73

TABLE 6-3

ENGINE CONTROL SPHERE PERFORMANCE DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507	S-IVB-506N
Temperature				
Required at engine start command (deg R)	N/A	N/A	277 ±30	287 ±20
At engine start command (deg R)	271	292	290	298
At engine cutoff command (deg R)	251	273	246	252
Pressure				
Required at engine start command (psia)	2,800 to 3,450	2,800 to 3,450	2,800 to 3,450	2,800 to 3,450
At engine start command (psia)	3,074	3,048	2,974	2,933*
At engine cutoff command (psia)	2,822	2,825	1,922	1,987*
Mass				
At engine start command (lbm)	2.00	**	1.88	1.81
After engine cutoff command (lbm)	2.00	**	1.46	1.43
Total helium usage*** (lbm)	0.48	**	0.42	0.38

N/A Not applicable

* Pressures are lower than usual because of low GSE regulator setting.

** Engine control sphere helium mass at any time is insignificant because it is tied into the LOX and LH2 tank ambient repressurization spheres.

*** Usage is calculated from flowrates and burn times.

TABLE 6-4

COMPARISON OF COMPUTER PROGRAM RESULTS

PROGRAM	INPUT	METHOD	RESULTS (at ESC +60 sec)
G105 Mode 3	LOX and LH_2 flowmeters, pump discharge pressures and temperatures, chamber pressures, chamber thrust area	This program is used only for propellant consumption. Flowrates are computed from flowmeter data and propellant densities. Mass consumptions are obtained by integrating the flowrates.	W_T = 534.3 lbm/sec W_{LOX} = 452.2 lbm/sec W_{LH_2} = 82.1 lbm/sec
PA53	Thrust chamber pressure, chamber throat area	The C_F is computed from equation $C_F = f\ (P_c)$ and thrust is computed from equation $F = C_F\ A_t\ P_c$. The impulse is determined from integrated thrust.	Refer to paragraph 6.3.3.
PA63	Pump inlet and outlet conditions, PU valve position, chamber pressure, turbine inlet and outlet conditions, flowmeter speed	Math models of rocket engine components are linked together by program which iterates among the component models until an operating point is reached where the power required by the pumps "balances" the power available from the turbines.	F = 226,768 lbf $\dot{W}_T$ = 534.9 lbm/sec I_{sp} = 424.0 MR = 5.53

TABLE 6-5 (Sheet 1 of 2)

DATA INPUTS TO COMPUTER PROGRAMS

PARAMETER	PROGRAM	SELECTION	REASON	BIAS	REASON
Chamber Press	G-105 PA63 PA53	D0001	Close agreement between (H/W) and (T/M)	-16.2 psi	-15 psi bias for P_c purge effect -1.2 psi bias to obtain rated ISP
LH_2 Pump Discharge Press	G-105-1 PA63	D0008 (T/M)	Close agreement between (H/W) and (T/M)	0	
LH_2 Pump Discharge Temperature	G-105-1 PA63	C0134 (T/M)	Close agreement between (H/W) and (T/M)	0	
LOX Pump Discharge Pressure	G-105-1 PA63	D0522 (H/W)	Least noisy	0	
LOX Pump Discharge Temperature	G-105-1 PA63	C0133 (T/M)	Close agreement between (H/W) and (T/M)	0	
LOX Flowrate	G-105-1 PA63	F0001 (T/M)	Close agreement between (H/W) and (T/M)	-18.76 gpm	Agree with actual pip count
LH_2 Flowrate	G-105-1 PA63	F0002 (T/M)	Close agreement between (H/W) and (T/M)	-65.12 gpm	Agree with actual pip count
LH_2 Pump Inlet Pressure	PA63	D0002 (T/M)	Close agreement between (H/W) and (T/M)	+0.3 psi	Compare to ullage pressure prior to flow
LH_2 Pump Inlet Temperature	PA63	C0003 (T/M)	Close agreement between (H/W) and (T/M)	0	

TABLE 6-5 (Sheet 2 of 2)

DATA INPUTS TO COMPUTER PROGRAMS

PARAMETER	PROGRAM	SELECTION	REASON	BIAS	REASON
LOX Pump Inlet Pressure	PA63	D0003	Close agreement between (H/W) and (T/M)	-0.2 psi	Compare to ullage pressure prior to flow
LOX Pump Inlet Temperature	PA63	C0004 (T/M)	Close agreement between (H/W) and (T/M)	0	
PU Valve Position	PA63	G0010 (T/M)	Close agreement between (H/W) and (T/M)	0	

TABLE 6-6 (Sheet 1 of 2)

ENGINE PERFORMANCE

PARAMETER	CLOSED PU VALVE OPERATION			REFERENCE MIXTURE RATIO OPERATION			OVERALL PERFORMANCE 90% TO ECC		
	ACTUAL	PREDICTED	% DEV	ACTUAL	PREDICTED	% DEV	ACTUAL	PREDICTED	% DEV
Thrust (lbf)	227,118	228.180	0.5	201,738	203,912	1.1	211,602	211,459	0.1
Total flowrate (lbm/sec)	534.87	538.86	0.7	472.44	479.02	1.4	495.45	497.86	0.5
LOX flowrate (lbm/sec)	452.30	456.07	0.8	392.62	398.91	1.6	414.81	417.10	0.5
LH_2 flowrate (lbm/sec)	82.57	82.79	0.7	79.81	80.11	1.2	80.64	80.75	0.8
Engine mixture ratio	5.478	5.509	0.6	4.919	4.979	1.2	5.131	5.153	0.4
Specific impulse (sec)	424.61	423.45	-0.3	426.99	425.69	-0.3	426.37	424.89	-0.4

TABLE 6-6 (Sheet 2 of 2)

ENGINE PERFORMANCE

PARAMETER	OPEN PU VALVE OPERATION (OPEN-LOOP PU)			NULL PU VALVE OPERATION (OPEN-LOOP PU)		
	ACTUAL	PREDICTED	% DEV	ACTUAL	PREDICTED	% DEV
Thrust (lbf)	172,530	172,760	0.1	198,834	201,668	1.4
Total flowrate (lbm/sec)	398.76	403.69	1.2	467.11	474.06	1.5
LOX flowrate (lbm/sec)	323.18	327.73	1.4	388.57	394.83	1.6
LH_2 flowrate (lbm/sec)	75.59	75.95	0.5	78.55	79.22	0.9
Engine mixture ratio	4.276	4.315	0.9	4.947	4.984	0.7
Specific impulse (sec)	432.66	427.96	-1.1	425.67	425.41	-0.1

TABLE 6-7

ENGINE THRUST VARIATIONS

Parameter	Limits	Time Period			
		Hardover Operation (5.5/1.0 EMR)	Transient From PU Vlv Cutback (Closed Loop) +75 Sec to PU Cutback (Open Loop)	Hardunder Operation (4.5/1.0 EMR)	Null Operation (5.0/1.0 EMR)
Variation in Predicted Minus Actual Mean Thrust Level (lbf)	Allowable	±4000	±8000	±4000	±4000
	Actual	+1200	+500	+310	+3100
	Predicted	—	—	—	—
Oscillation About Mean Thrust Level (lbf)	Allowable	±2500	±7500	±2500	±2500
	Actual	±1110	±2460	±800	±700
	Predicted	±650	±1400	±150	±250
Rate of Change of Thrust (lbf/sec)	Allowable	±500	±500	±500	±500
	Actual	+317	-181	232	+100
	Predicted	±100	±100	±100	±100
Thrust Acceleration (lbf/sec/sec)	Allowable	±125	±500	±125	±125
	Actual	+35	-40	-38	+22
	Predicted	—	—	—	—

TABLE 6-8 (Sheet 1 of 6)

ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
K0021 (K0021)	*Engine Start Command P/U			0	0	0
		K0007 (K0531)	Helium Control Solenoid Enrg P/U	Within 10 ms of K0021	002	002
		K0010 (K0454)	Thrust Chamber Spark on P/U	Within 10 ms of K0021	002	002
		K0011 (K0455)	Gas Generator Spark on P/U	Within 10 ms of K0021	002	002
		K0006 (K0535)	Ignition Phase Control Solenoid Enrg P/U	Within 20 ms of K0021	002	002
		K0012 (K0530)	Engine Ready D/O	Within 20 ms of K0006	005	003
		K0126 (K0558)	LOX Bleed Valve Closed P/U	Within 200 ms of K0007	143	141
		K0127 (K0557)	LH2 Bleed Valve Closed P/U	Within 200 ms of K0007	128	126
		K0020 (K0627)	ASI LOX Valve Open P/U	Within 20 ms of K0006	066	064

(KOXXX) Actual number from acceptance firing event recorder.

*Engine ready and stage separation signals (or simulation) are required before this command will be executed.

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 2 of 6)

ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
		K0119 (G506)	Main Fuel Valve Closed D/O	60 ±30 ms from K0006	067	065
		K0118 (G506)	Main Fuel Valve Open P/U	110 ±60 ms from K0119	177	110
K0008 (K0537)	*Ignition Detected			Within 250 ms of K0021 P/U	197	197
K0096 (K0536)	**Start Tank Disc Control Solenoid Enrg			1,120 ±20 ms from K0021 P/U	1,130	1,130
K0021 (K0021)	Engine Start D/O			200 ±20 ms from K0096 P/U	1,333	203
		K0123 (G508)	Start Tank Disc Valve Closed D/O	100 ±20 ms from K0096	1,288	158
		K0122 (G508)	Start Tank Disc Valve Open P/U	105 ±20 ms from K0123	1,346	058
K0005 (K0538)	Mainstage Control Solenoid Enrg			450 ±30 ms from K0096	1,580	450

*This signal must be received within 1,110 ±60 ms of K0021 P/U or cutoff will be initiated.

**An indication of fuel injection temperature of -150 ±40 deg F (or simulation) is required before this command will be executed. This command also actuates a 450 ±30 ms timer which controls the start of mainstage.

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 3 of 6)

ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
		K0096 (K0536)	Start Tank Disc Control Solenoid Enrg D/O	450 $\pm$30 ms from K0096	1,580	450
		K0121 (G507)	Main LOX Valve Closed D/O	50 $\pm$20 ms from K0005	1,634	054
		K0116 (G509)	Gas Generator Valve Closed D/O		1,682	
		K0122 (G508)	Start Tank Disc Valve Open D/O	95 $\pm$20 ms from K0096	1,707	127
		K0117 (G509)	Gas Generator Valve Open P/U		1,802	
		K0124 (G510)	LOX Turbine Bypass Valve Open D/O		1,792	
			LOX Turbine Bypass Valve 80% Closed	400 $^{+150}_{-50}$ ms from K0122	2,017	310
		K0123 (G508)	Start Tank Disc Valve Closed P/U	250 $\pm$40 ms from K0122	1,953	246
		K0125 (G510)	*LOX Turbine Bypass Valve Closed P/U		2,071	
KC158 (K0572)	Mainstage Press Switch #1 Depress D/O				3,262	

*Within 5,000 ms of K0005 (Normally = 500 ms)

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 4 of 6)

ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
K0159	Mainstage Press Switch #2 Depress D/O				3,263	
K0191 (K0610)	*Mainstage OK				3,261	
		K0120 (G507)	Main LOX Valve Open P/U	2,435 $\pm$145 ms from K0005	4,015	2,435
		K0010 (K0454)	Thrust Chamber Spark on D/O	3,300 $\pm$200 ms from K0005 P/U	4,881	3,301
		K0011 (K0455)	Gas Generator Spark On D/O	3,300 $\pm$200 ms from K0005 P/U	4,881	3,301
K0507	PU Activate Switch P/U				6,166	
K0507	PU Activate Switch D/O				350,429	
K2440	**PU Open Loop Reset D/O				350,566	
K2440	***PU Open Loop Reset P/U				410,370	

*One of these signals must be received within 4,410 $\pm$260 ms from K0021 P/U, or cutoff will be initiated. Signal occurs when LOX injection pressure is 500 $\pm$30 psig.

**Puts PU valve to full open position.

***Puts PU valve to null position.

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 5 of 6)

ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ECC	FROM SPECIFIED REFERENCE
K0013 (K0522) (K0539)	Engine Cutoff P/U (New time reference)			0	0	0
		K0005 (K0538)	Mainstage Control Solenoid Enrg D/O	Within 10 ms of K0013	003	003
		K0006 (K0535)	Ignition Phase Control Solenoid Enrg D/O	Within 10 ms of K0013	0	0
		K0020 (K0627)	ASI LOX Valve Open D/O		020	
		K0120 (G507)	Main Oxidizer Valve Open D/O	50 $\pm$15 ms from K0005	074	071
		K0117 (G509)	Gas Generator Valve Open D/O	75 $^{+25}_{-35}$ ms from K0006	034	034
		K0118 (G506)	Main Fuel Valve Open D/O	90 $\pm$25 ms from K0006	099	099
		K0121 (G507)	Main Oxidizer Valve Closed P/U	120 $\pm$15 ms from K0120	205	131
		K0116 (G509)	Gas Generator Valve Closed P/U	500 ms from K0006	092	092
		K0119 (G506)	Main Fuel Valve Closed P/U	225 $\pm$25 ms from K0118	379	280

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 6 of 6)

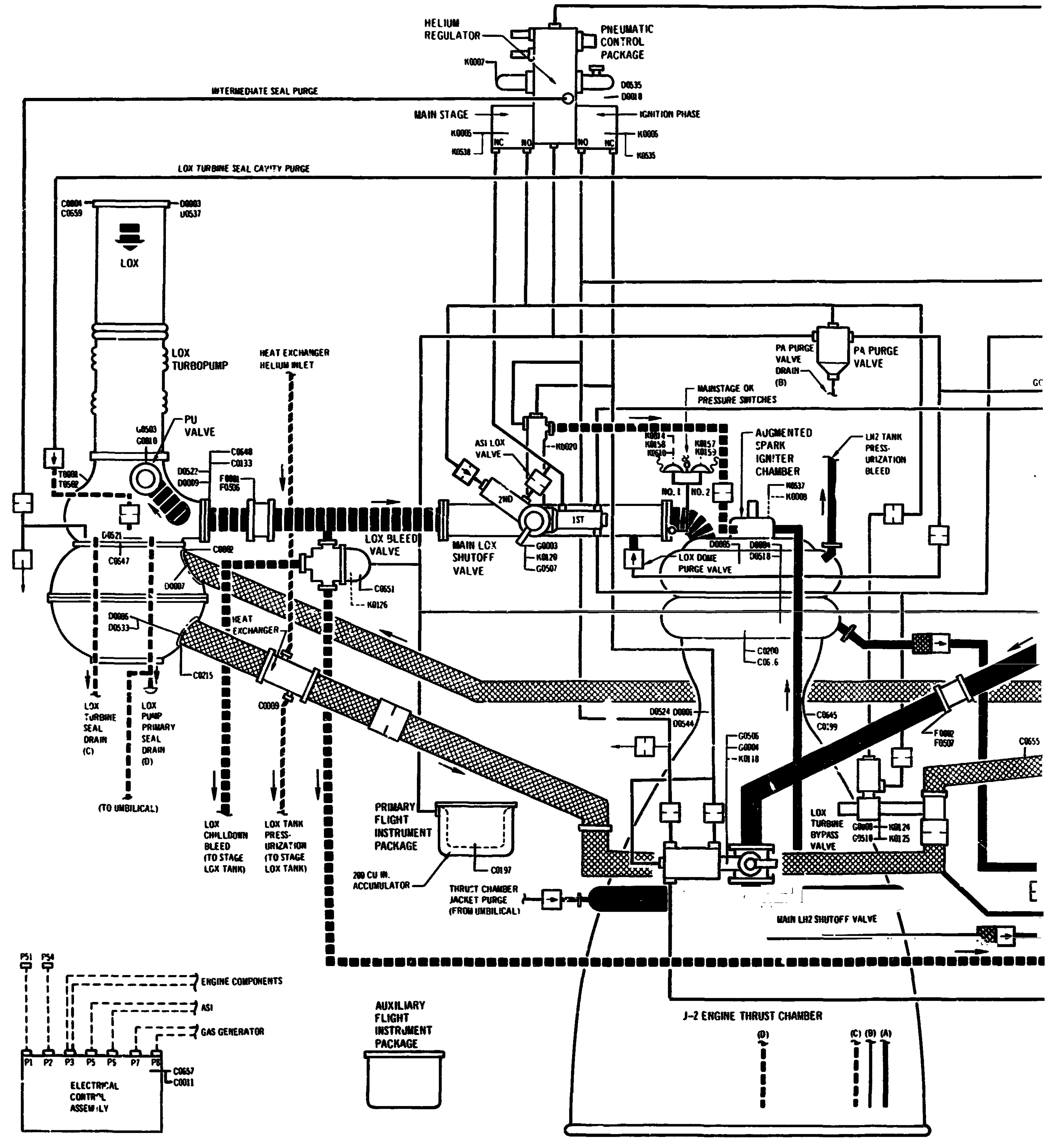
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS. NO.	EVENT AND COMMENT	MEAS. NO.	EVENT AND COMMENT		FROM ECC	FROM SPECIFIED REFERENCE
K0158 (K0572)	*Mainstage Press Switch A Depress P/U				181	
K0159 (K0573)	Mainstage Press Switch B Depress P/U			*	181	
K0191 (K0610)	Mainstage OK D/O			*	183	
K0007 (K0531)	Helium Control Solenoid Enrg D/O			1,000 ±110 ms from K0013	987	987
		K0125 (G510)	Oxidizer Turbine Bypass Valve Closed D/O		226	
		K0124 (G510)	Oxidizer Turbine Bypass Valve Open P/U	10,000 ms from K0005	954	951
K0126 (K0558)	LOX Bleed Valve Closed D/O			30,000 ms from K0005	8,429	8,426
K0127 (K0557)	LH2 Bleed Valve Closed D/O			30,000 ms from K0005	7,748	7,745

*Signal drops out when pressure reaches 425 ±25 psig.

P/U - Pickup

D/O - Dropout


HELIUM REGULATOR
PNEUMATIC CONTROL PACKAGE
K0007
D0535
D0018
INTERMEDIATE SEAL PURGE
MAIN STAGE
IGNITION PHASE
K0005
K0538
K0006
K0535
NC
NO
LOX TURBINE SEAL CAVITY PURGE
C0004
C0659
D0003
D0537
LOX
LOX TURBOPUMP
HEAT EXCHANGER HELIUM INLET
PU VALVE
G0503
G0010
T0001
T0502
C0648
C0133
D0522
D0009
F0001
F0506
C0521
C0647
C0002
D0007
D0005
D0533
HEAT EXCHANGER
C0215
LOX BLEED VALVE
C0651
K0126
MAIN LOX SHUTOFF VALVE
G0003
K0129
G0507
ASI LOX VALVE
K0020
2ND
1ST
MAINSTAGE OK PRESSURE SWITCHES
NO. 1
NO. 2
AUGMENTED SPARK IGNITER CHAMBER
K0537
K0008
LOX DOME PURGE VALVE
PA PURGE VALVE DRAIN
(B)
PA PURGE VALVE
LH2 TANK PRESS-URIZATION BLEED
C0200
C0616
C0645
C0199
D0524
D0001
D0544
G0506
G0004
K0118
F0002
F0507
C0655
LOX TURBINE SEAL DRAIN (C)
LOX PUMP PRIMARY SEAL DRAIN (D)
(TO UMBILICAL)
C0009
LOX CHILLDOWN BLEED (TO STAGE LOX TANK)
LOX TANK PRESS-URIZATION (TO STAGE LOX TANK)
PRIMARY FLIGHT INSTRUMENT PACKAGE
200 CU IN. ACCUMULATOR
C0197
THRUST CHAMBER JACKET PURGE (FROM UMBILICAL)
LOX TURBINE BYPASS VALVE
G0008
G0510
K0124
K0125
MAIN LH2 SHUTOFF VALVE
J-2 ENGINE THRUST CHAMBER
(D)
(C) (B) (A)
P51
P54
ENGINE COMPONENTS
ASI
GAS GENERATOR
P1
P2
P3
P5
P6
P7
P8
C0657
C0011
ELECTRICAL CONTROL ASSEMBLY
AUXILIARY FLIGHT INSTRUMENT PACKAGE

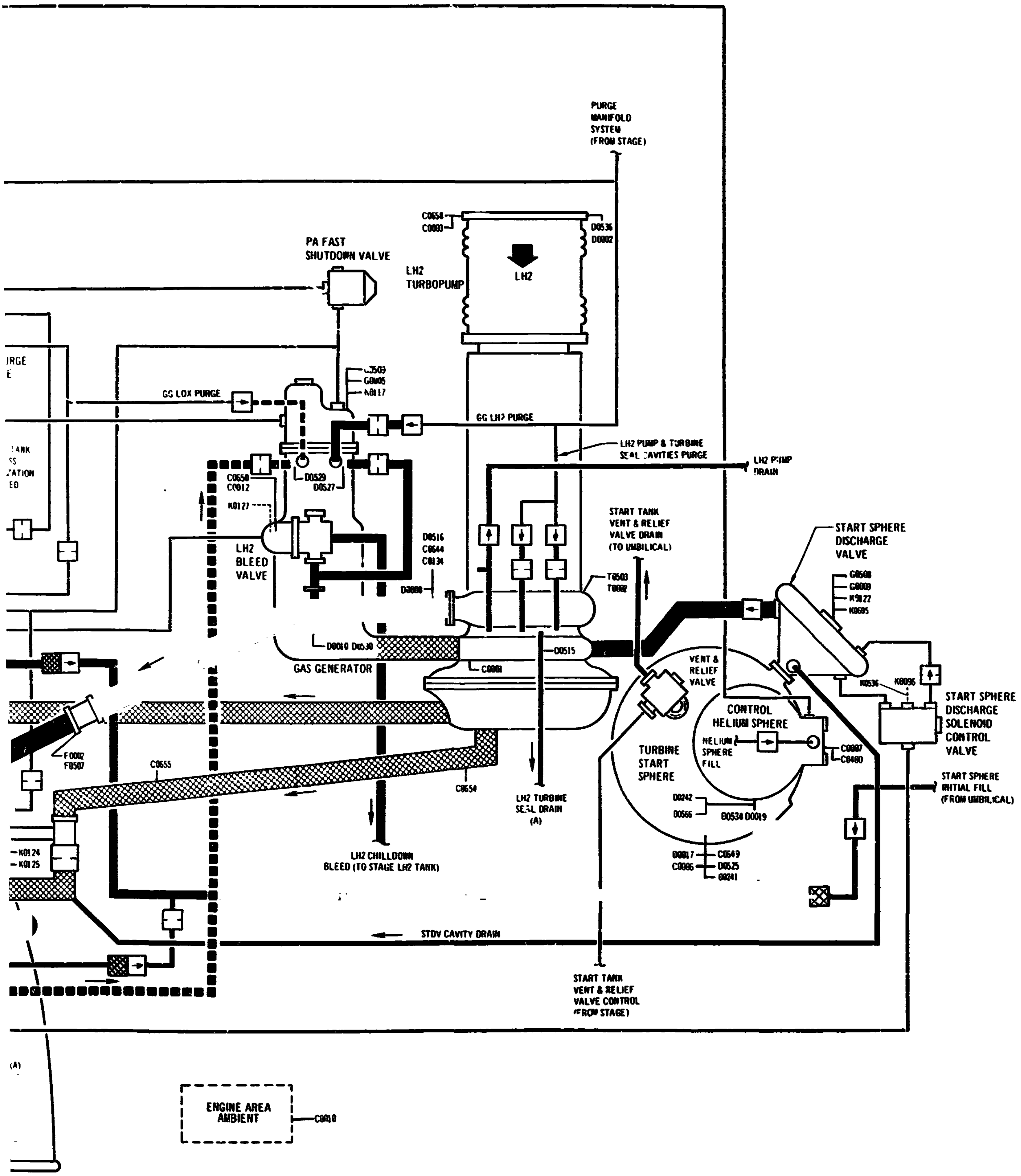


Figure 6-1. J-2 Engine System and Instrumentation

FOLDOUT FRAME 2

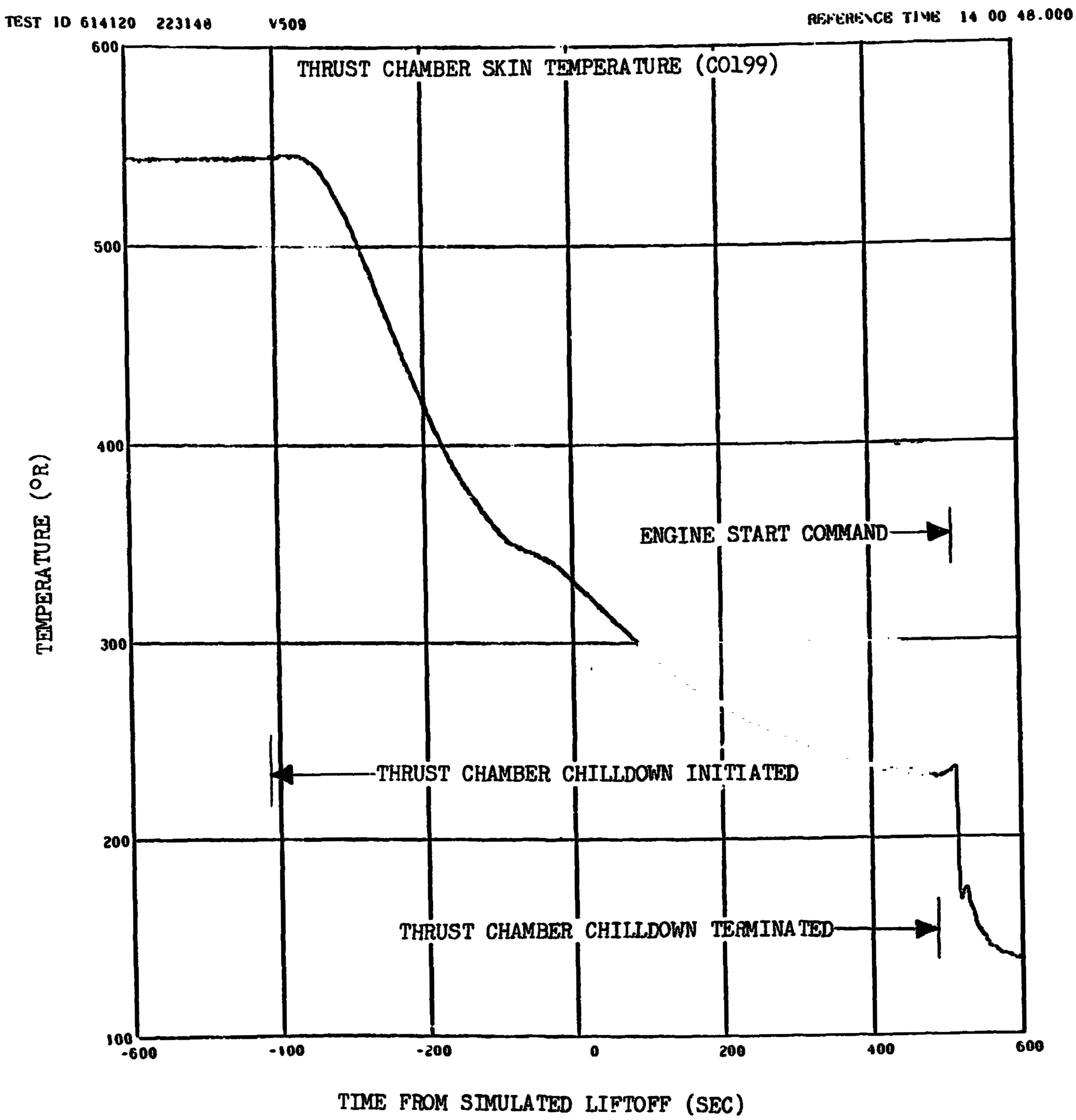


Figure 6-2. Thrust Chamber Chilldown

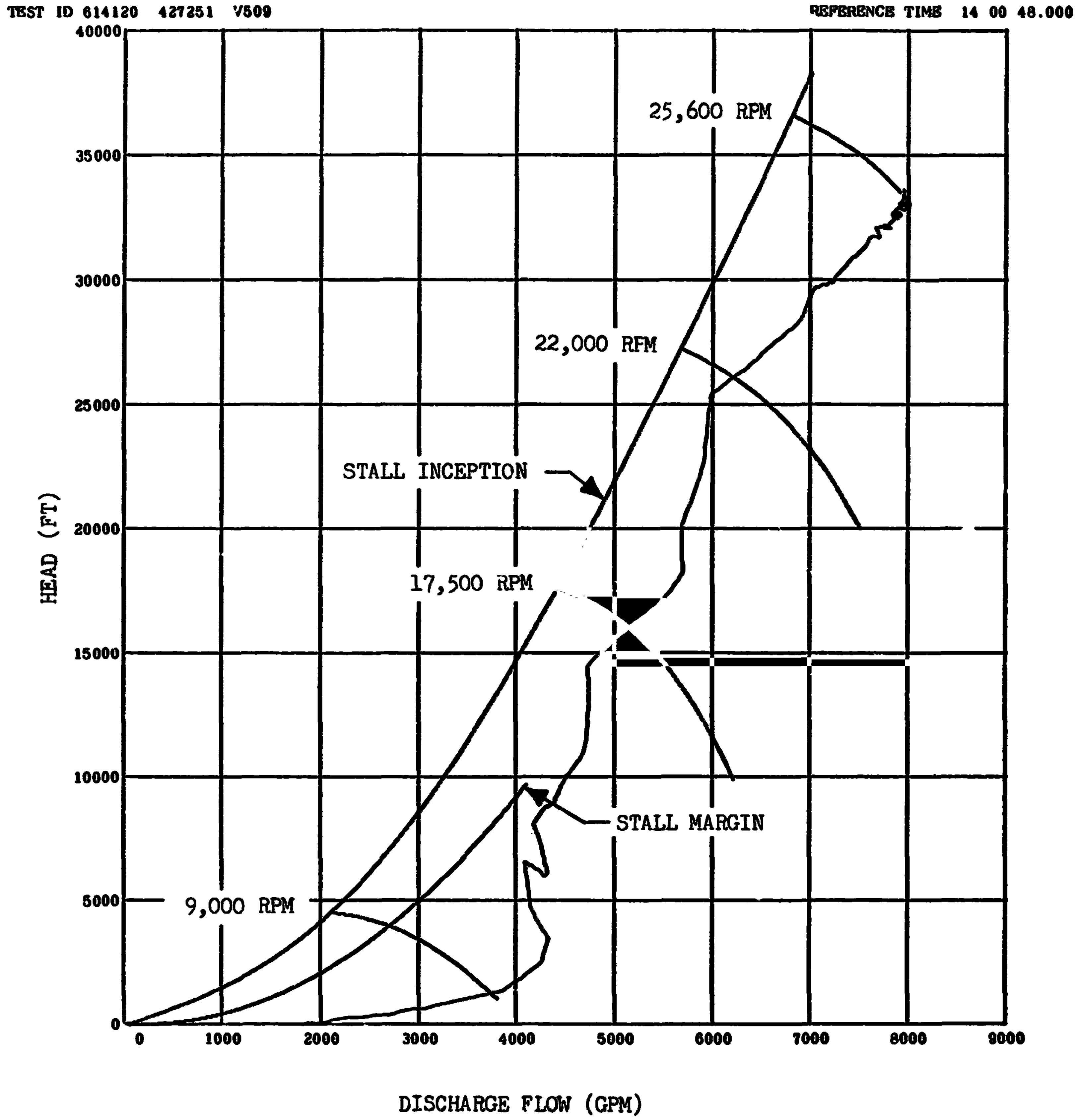


Figure 6-3. LH2 Pump Performance During Engine Start

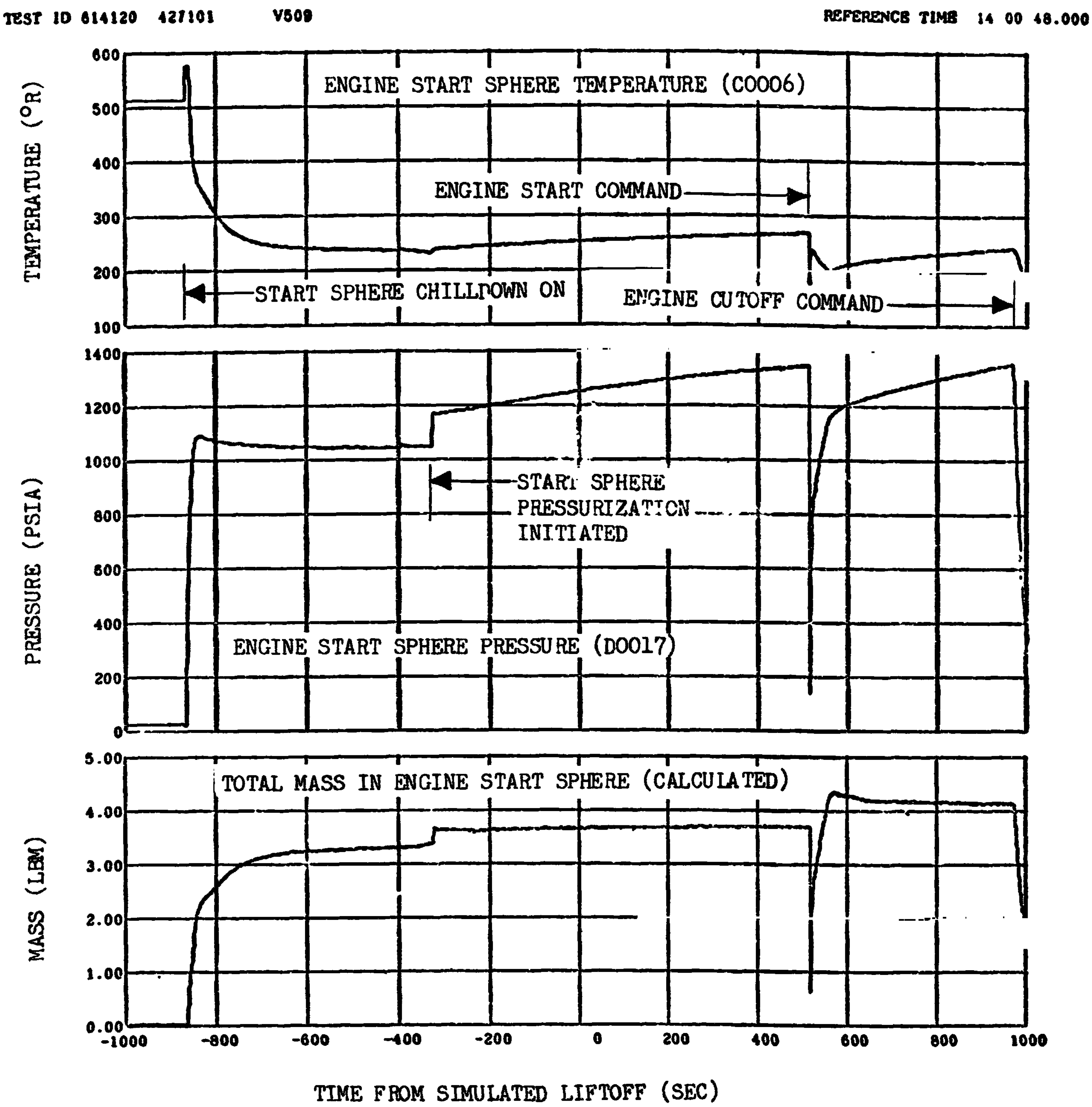


Figure 6-4. Engine Start Sphere Performance

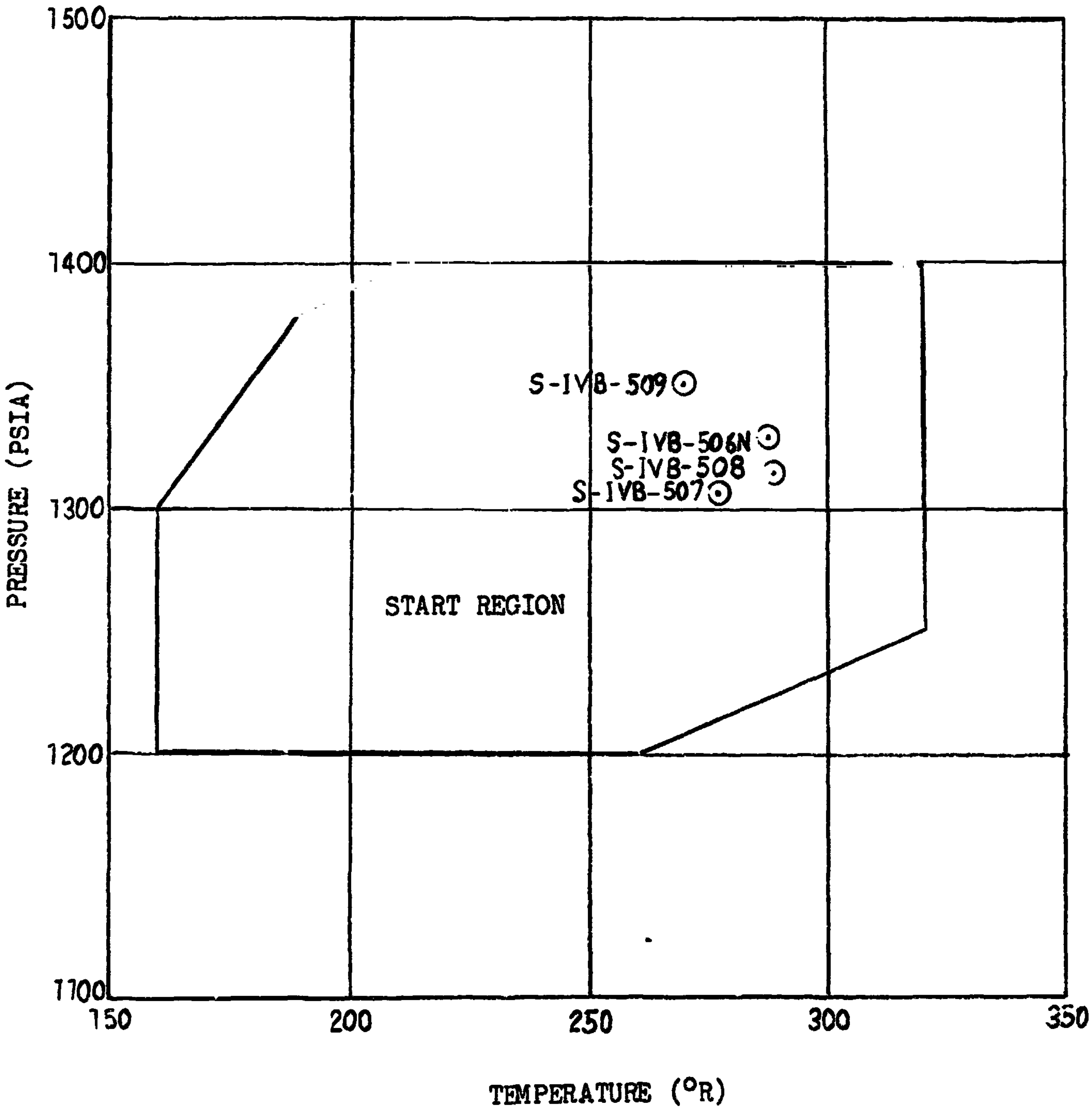


Figure 6-5. Engine Start Sphere Critical Limits at Engine Start

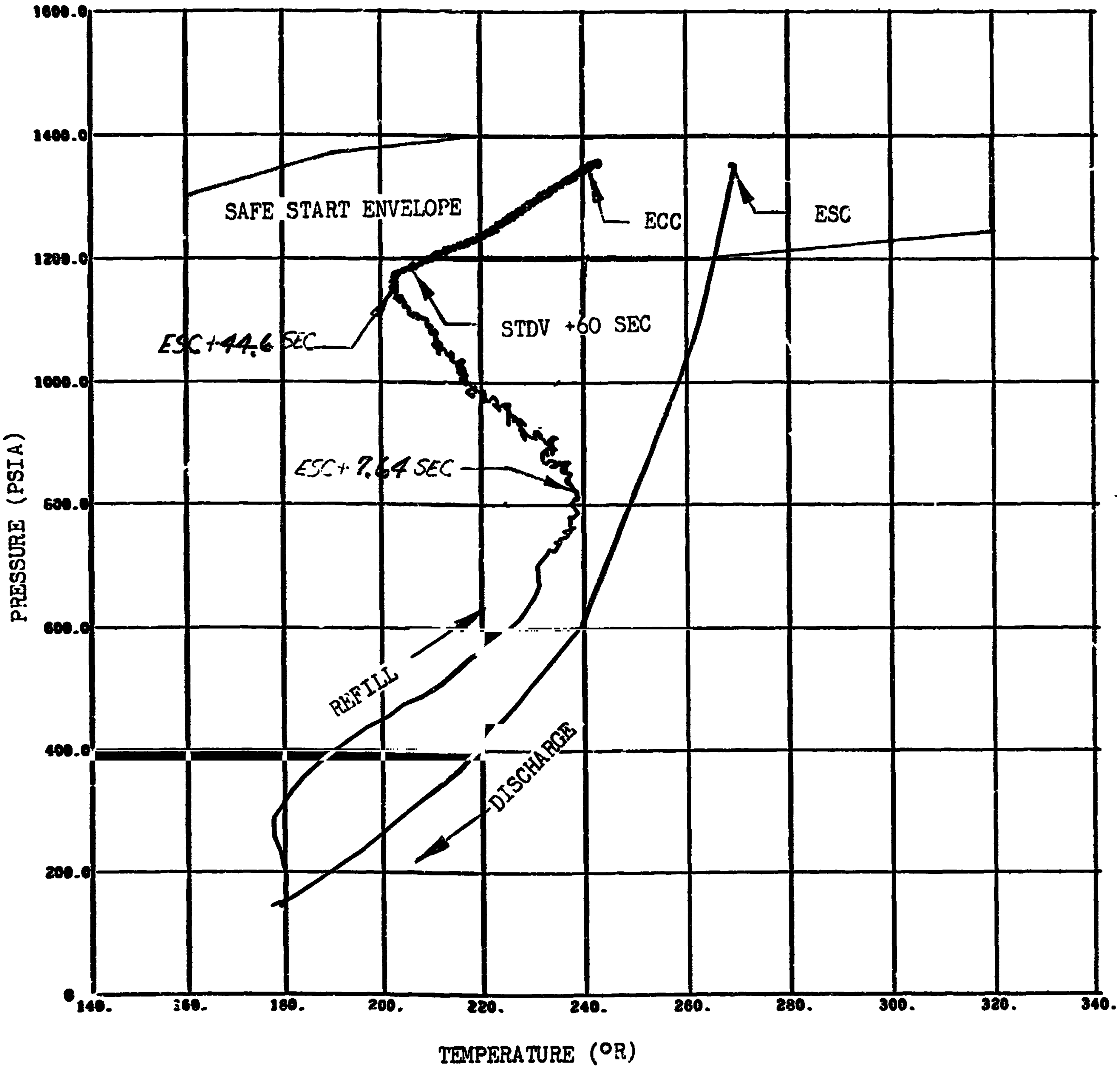
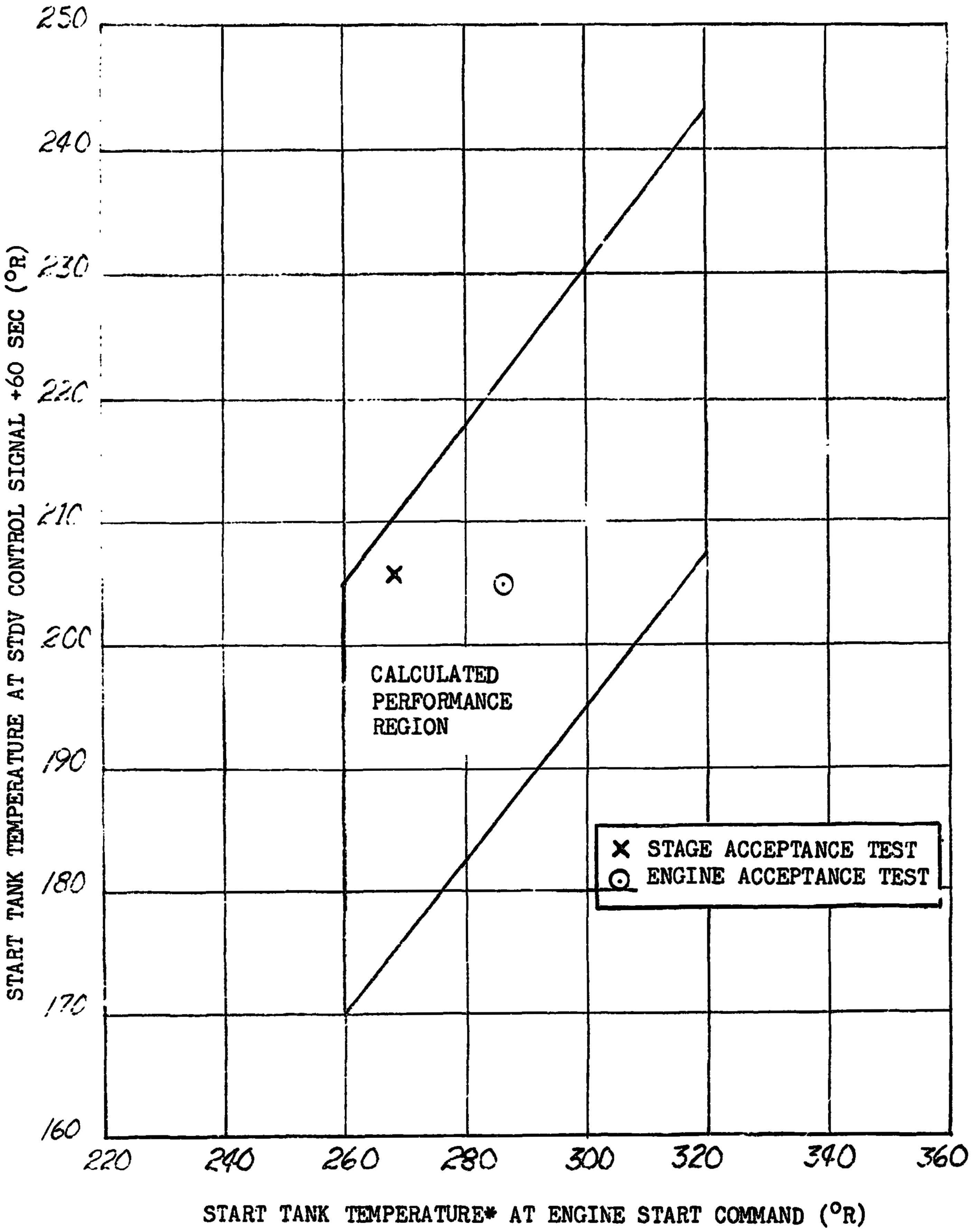


Figure 6-6. Start Tank Refill Performance



*CORRECTED TO ZERO DIFFERENTIAL WITH RESPECT TO HELIUM TANK TEMPERATURE

Figure 6-7. S-IVB-509 Restart Capability

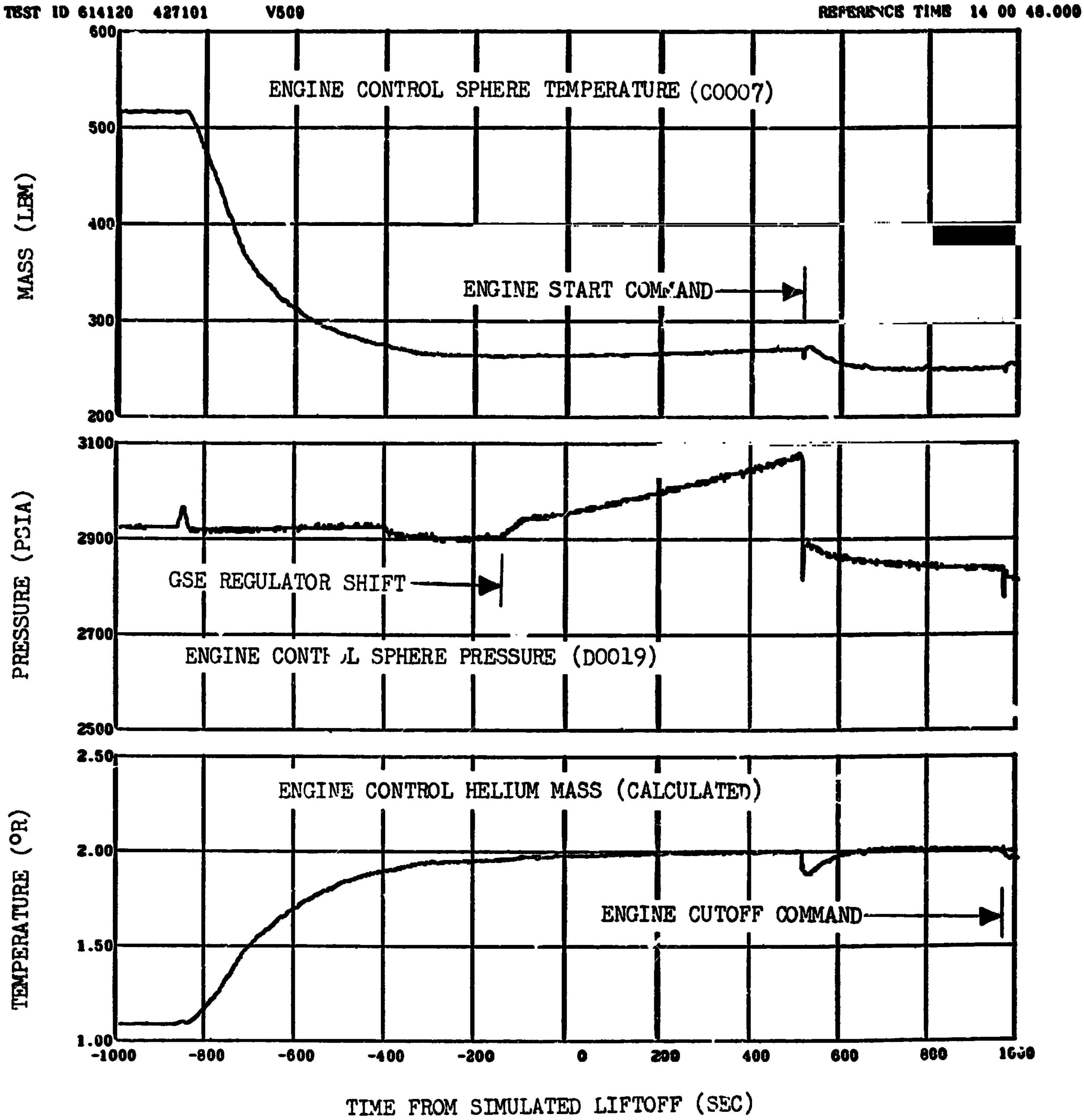


Figure 6-8. Engine Control Sphere Performance

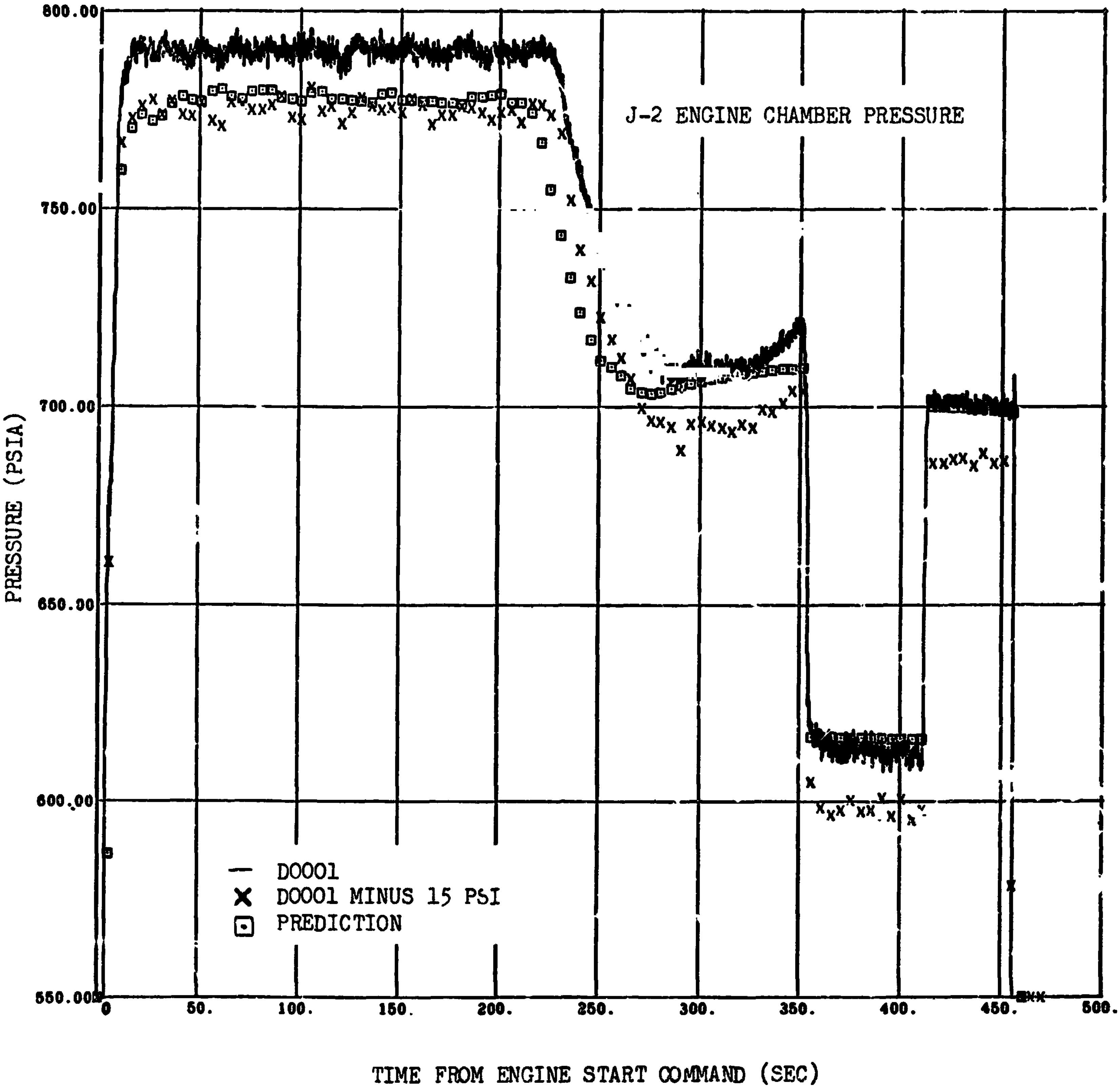


Figure 6-9. J-2 Engine Chamber Pressure

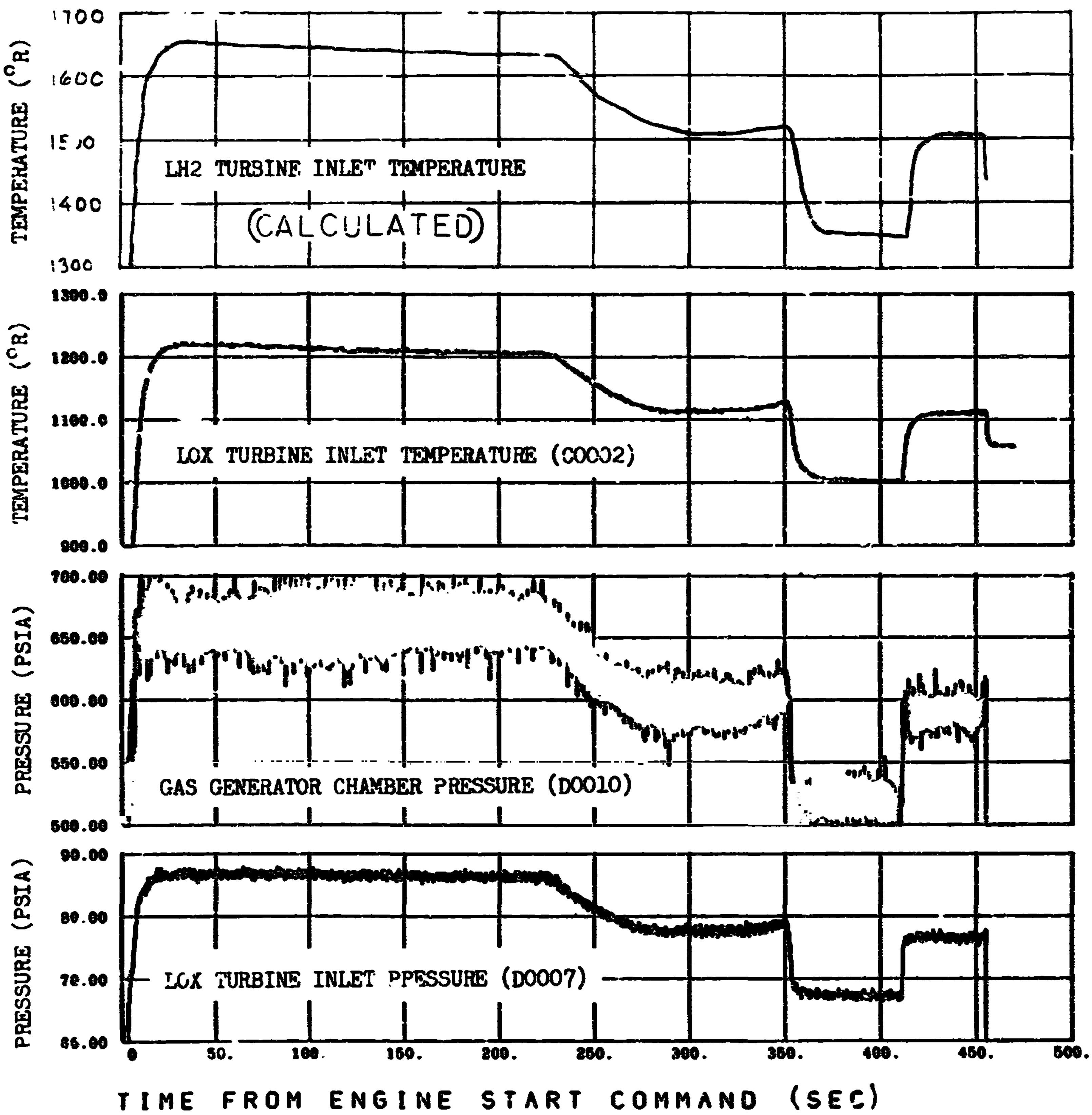


Figure 6-10. Turbopump Operating Characteristics (Sheet 1 of 2)

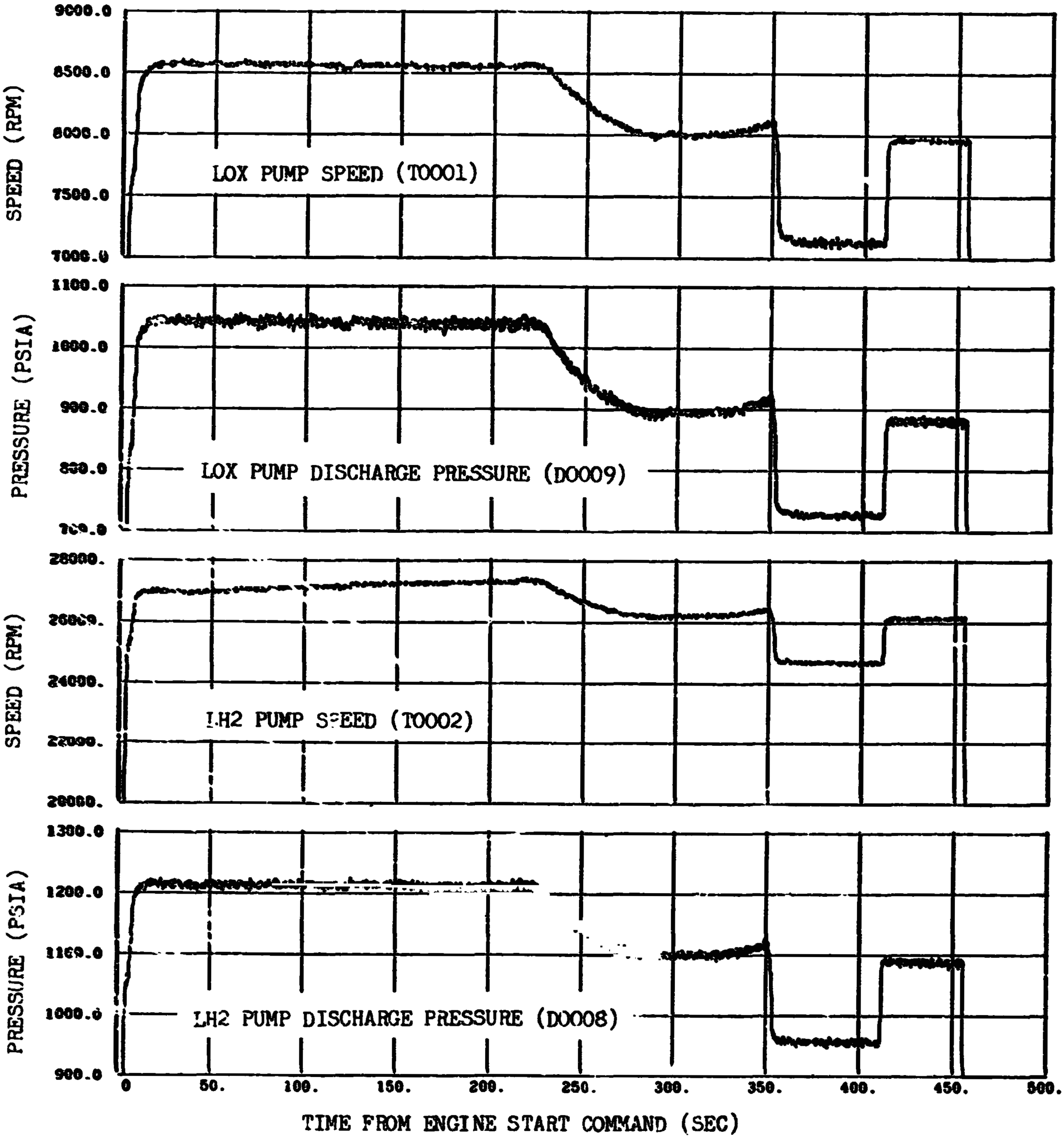


Figure 6-10. Turbopump Operating Characteristics (Sheet 2 of 2)

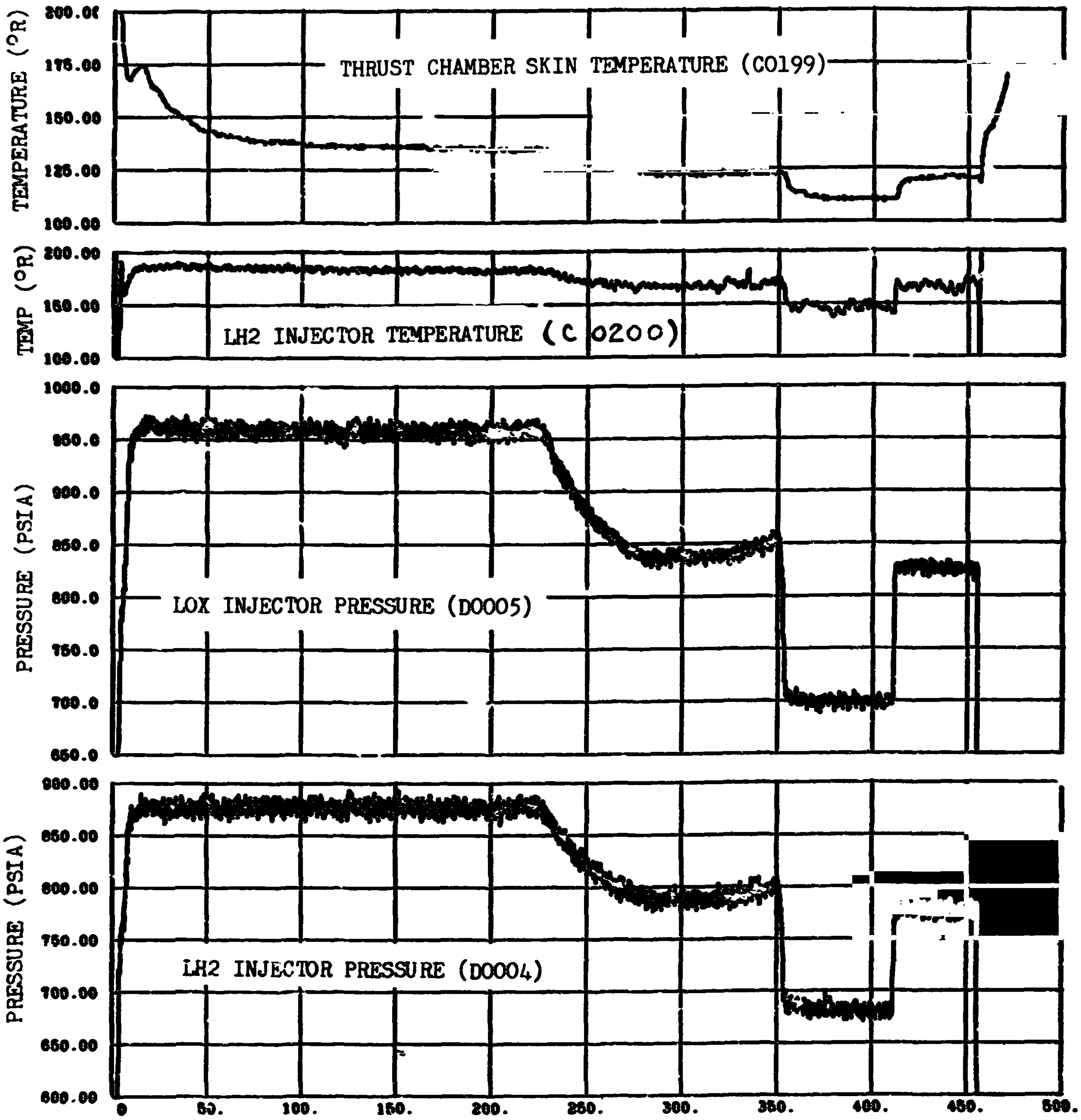


Figure 6-11. J-2 Engine Injector Supply Conditions

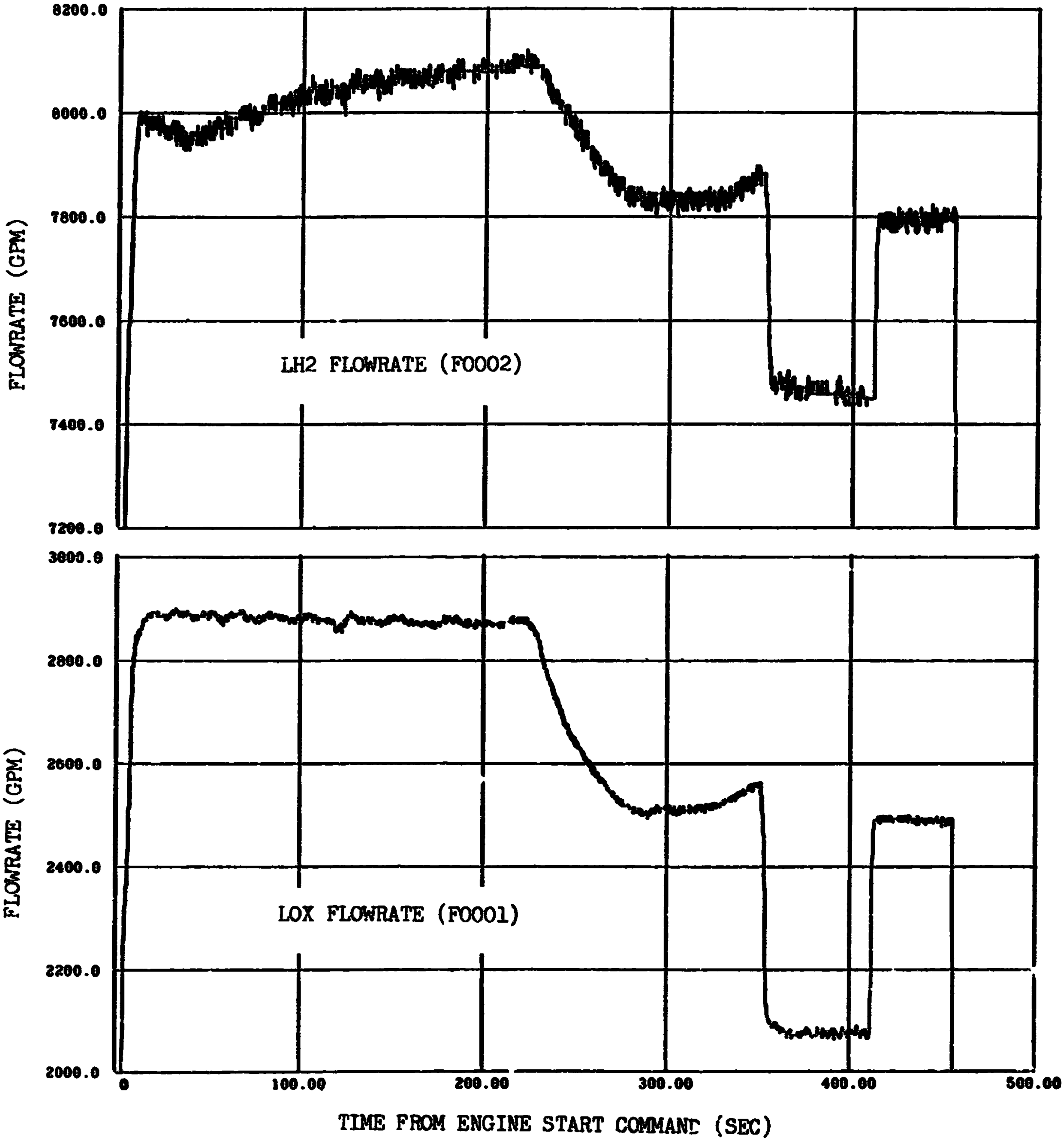


Figure 6-12. LOX and LH2 Flowrate

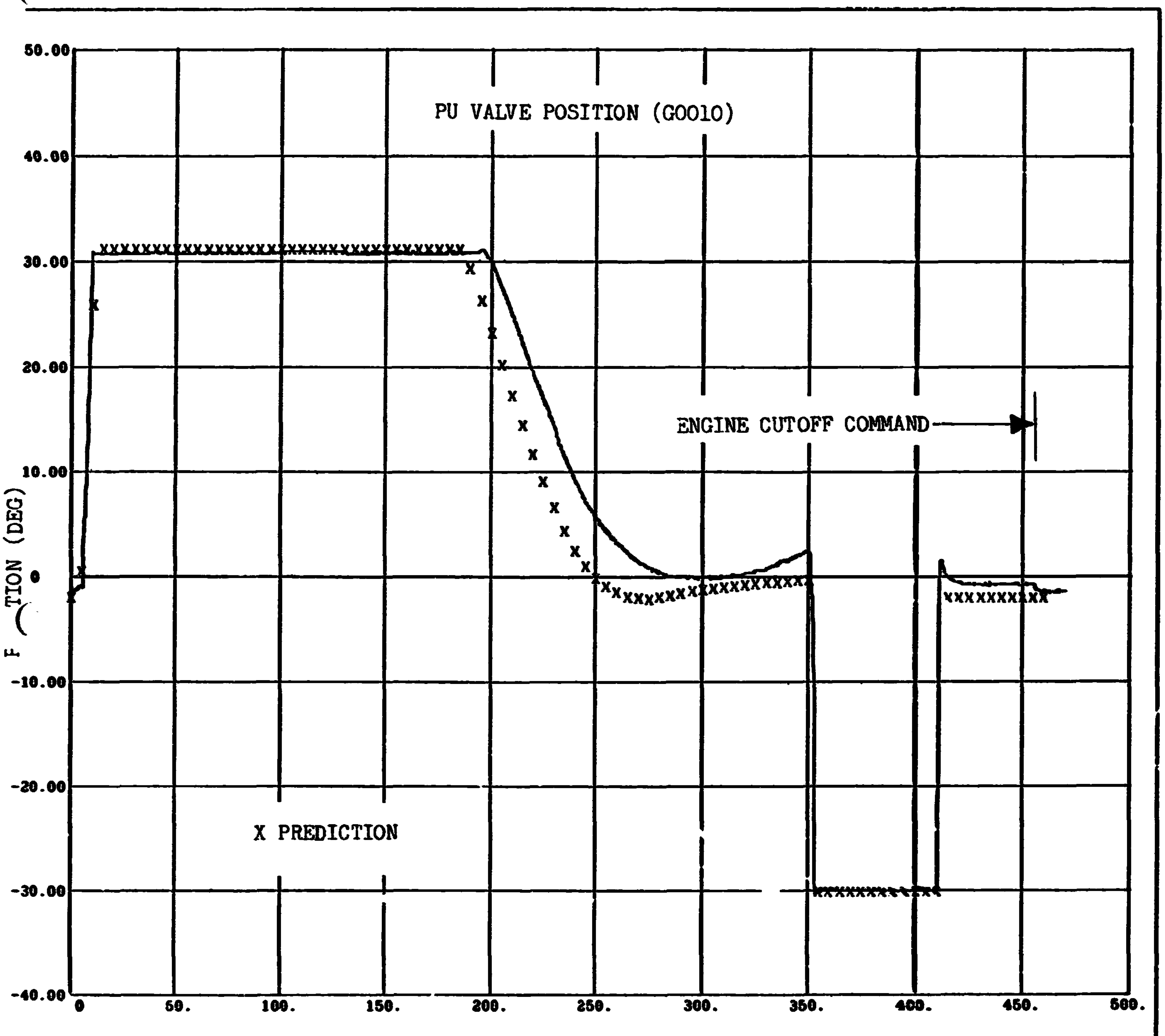


Figure 6-13. PU Valve Position

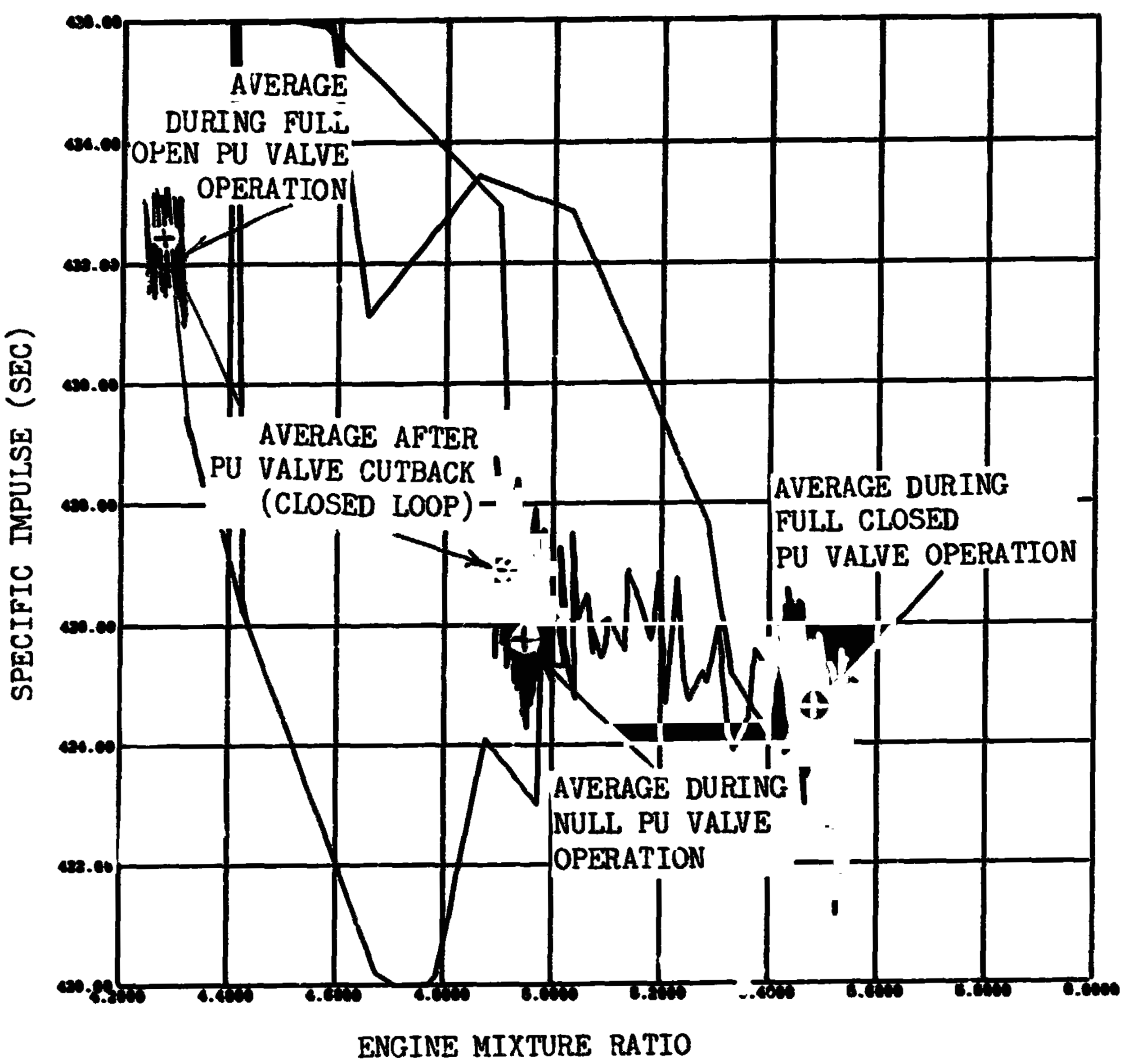


Figure 6-14. Engine Mixture Ratio vs Specific Impulse

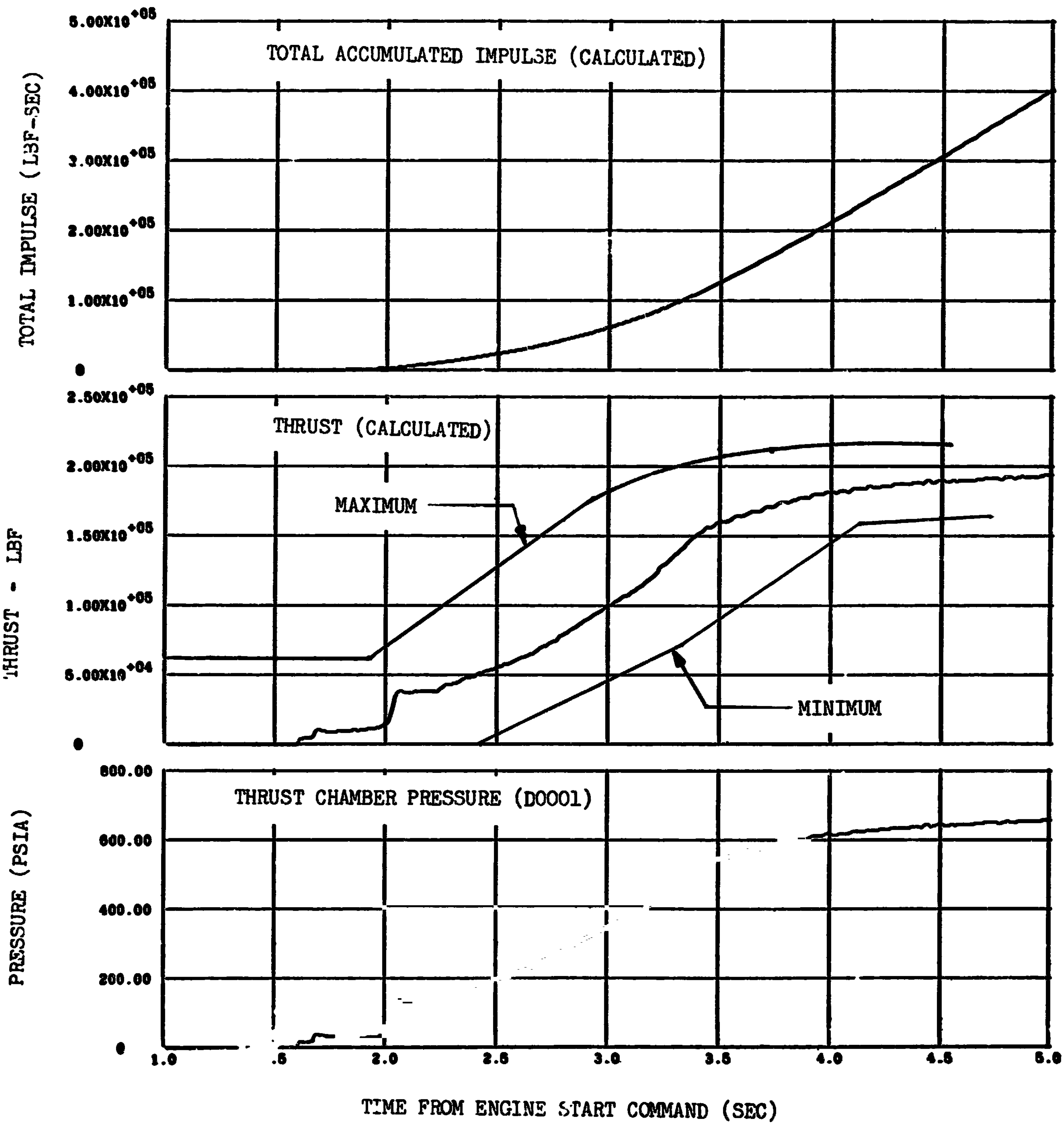


Figure 6-15. Engine Start Transient Characteristics

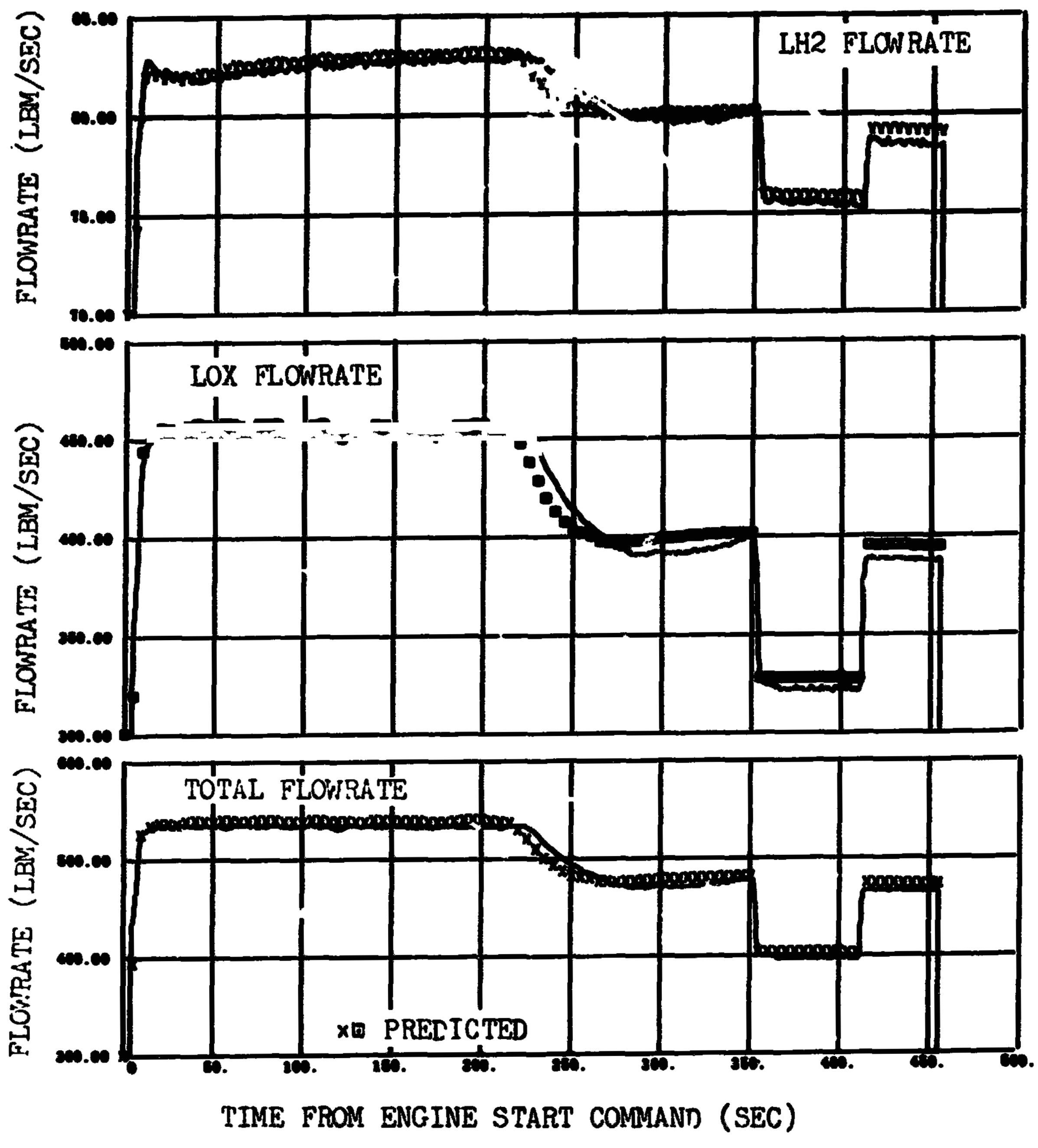


Figure 6-16. Engine Steady State Performance (Sheet 1 of 3)

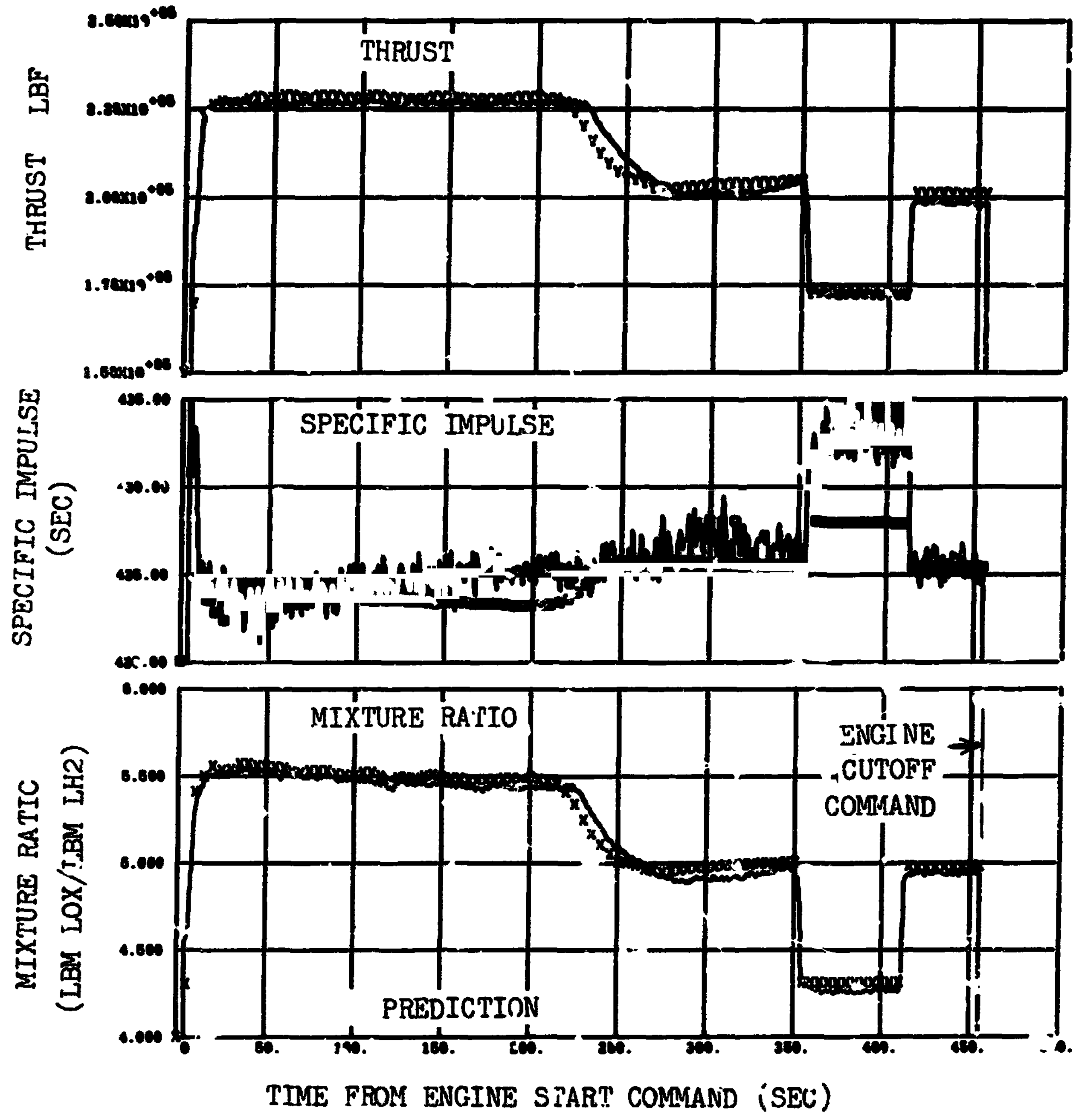


Figure 6-16. Engine Steady State Performance (Sheet 2 of 3)

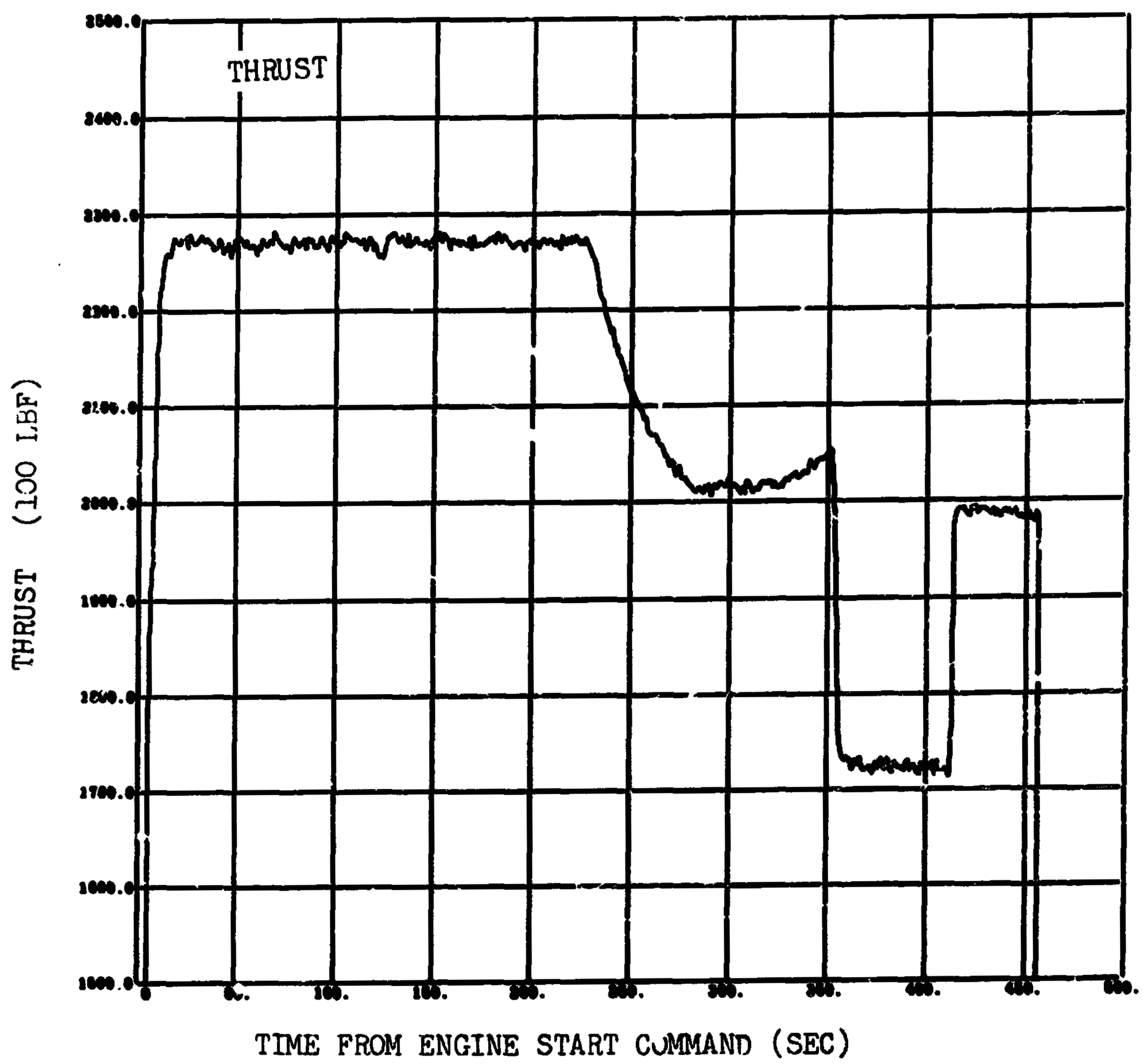


Figure 6-16. Engine Steady State Performance (Sheet 3 of 3)

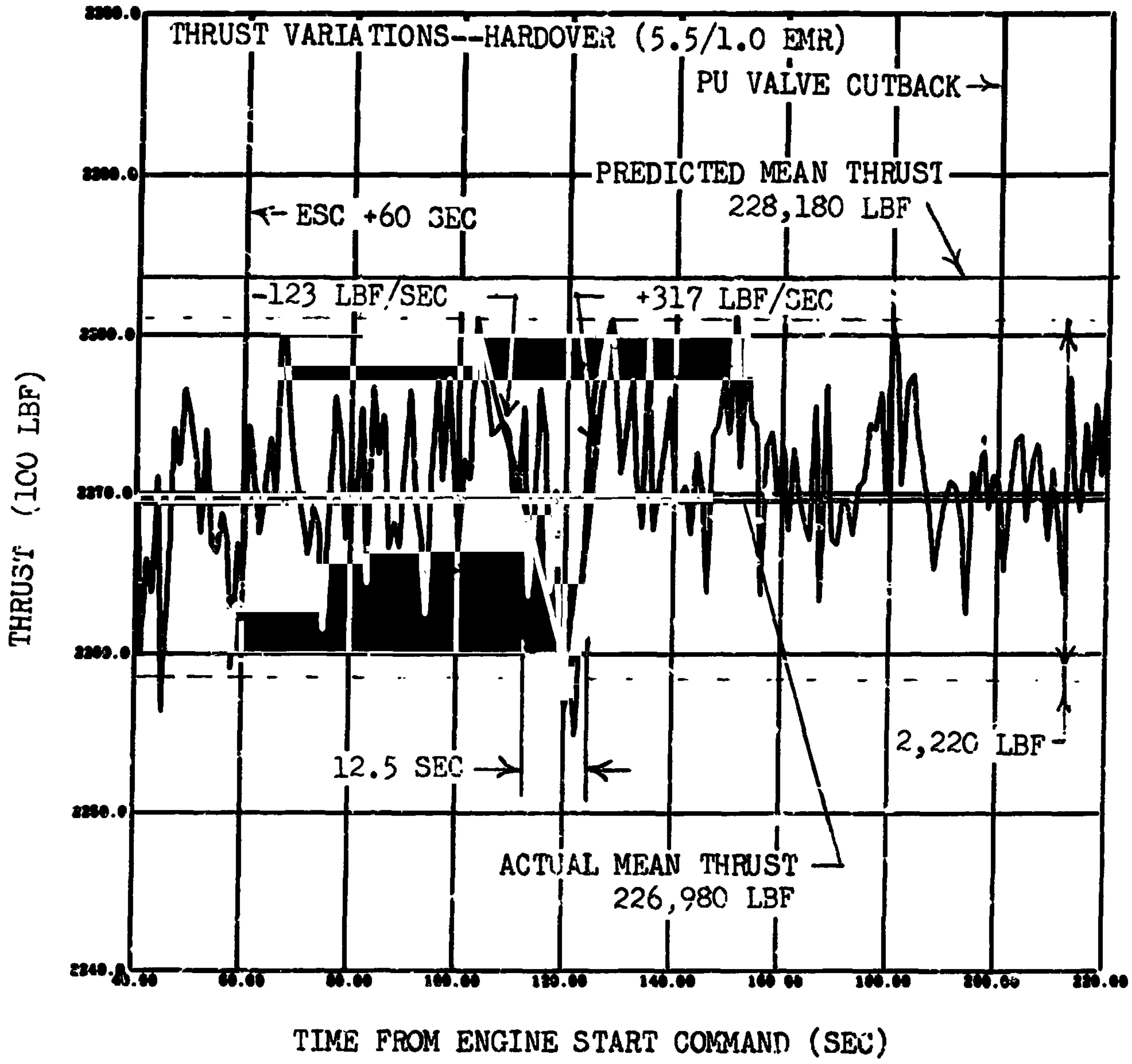


Figure 6-17. Thrust Variation (Sheet 1 of 4)

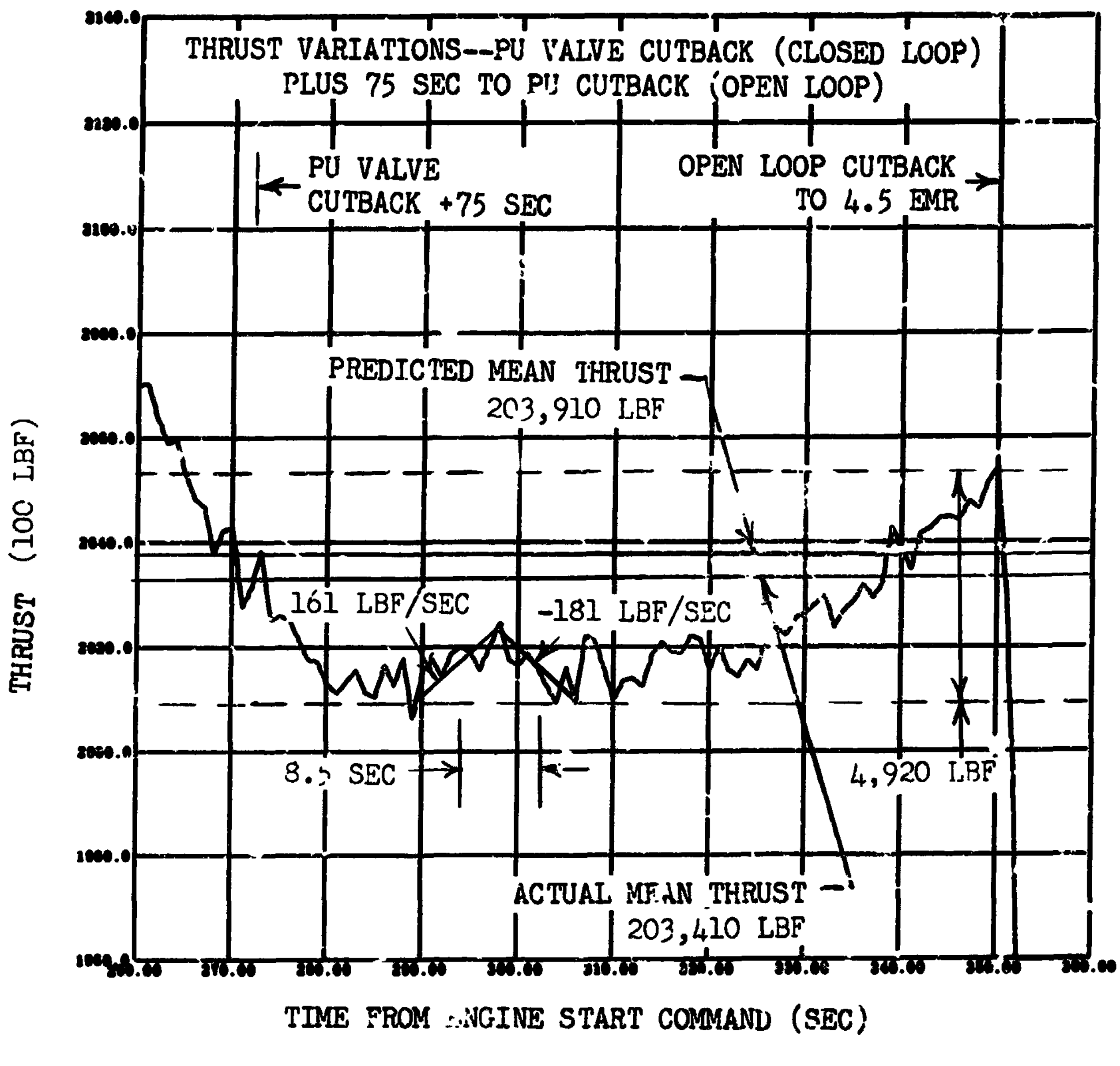


Figure 6-17. Thrust Variation (Sheet 2 of 4)

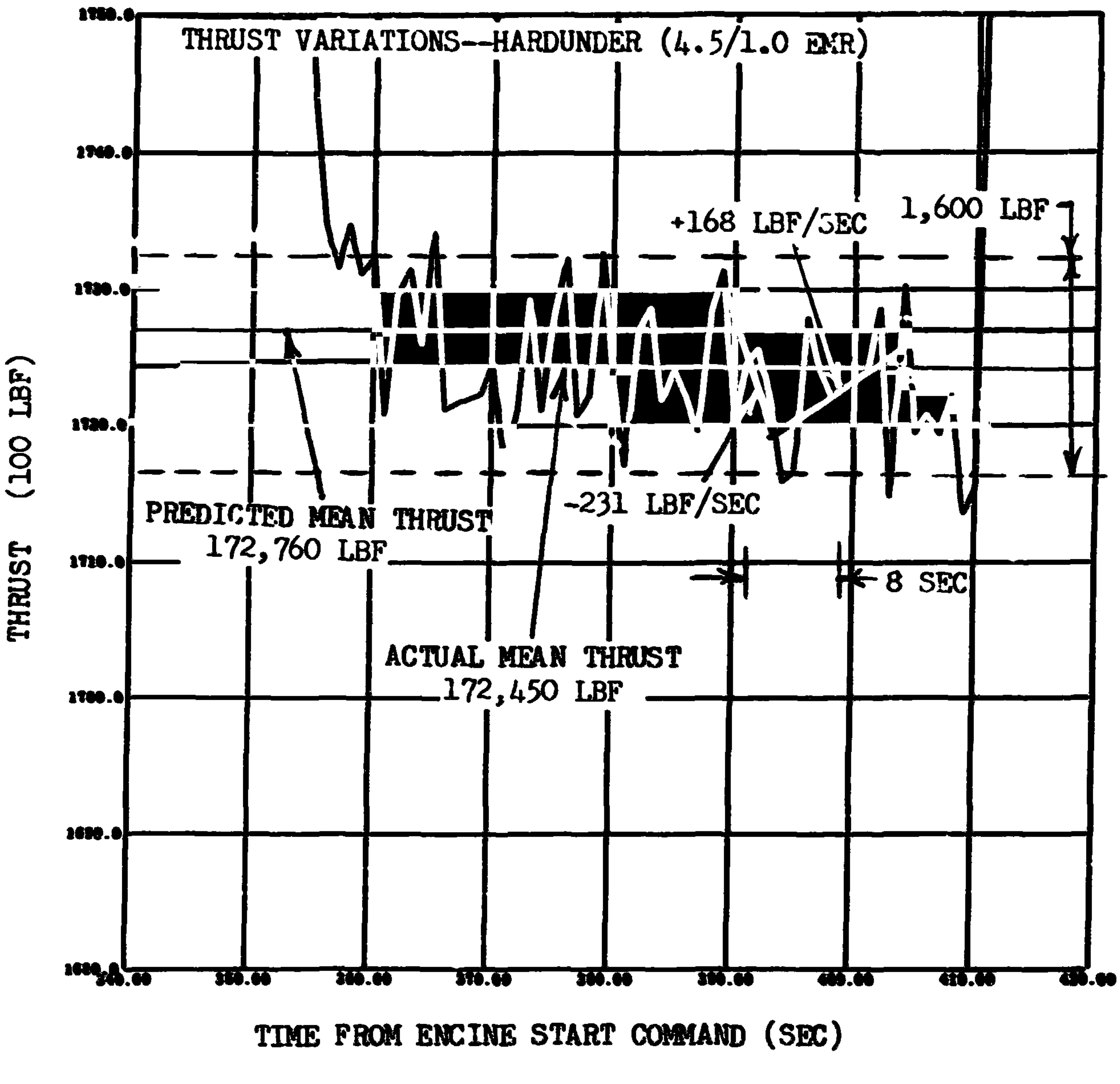


Figure 6-17. Thrust Variation (Sheet 3 of 4)

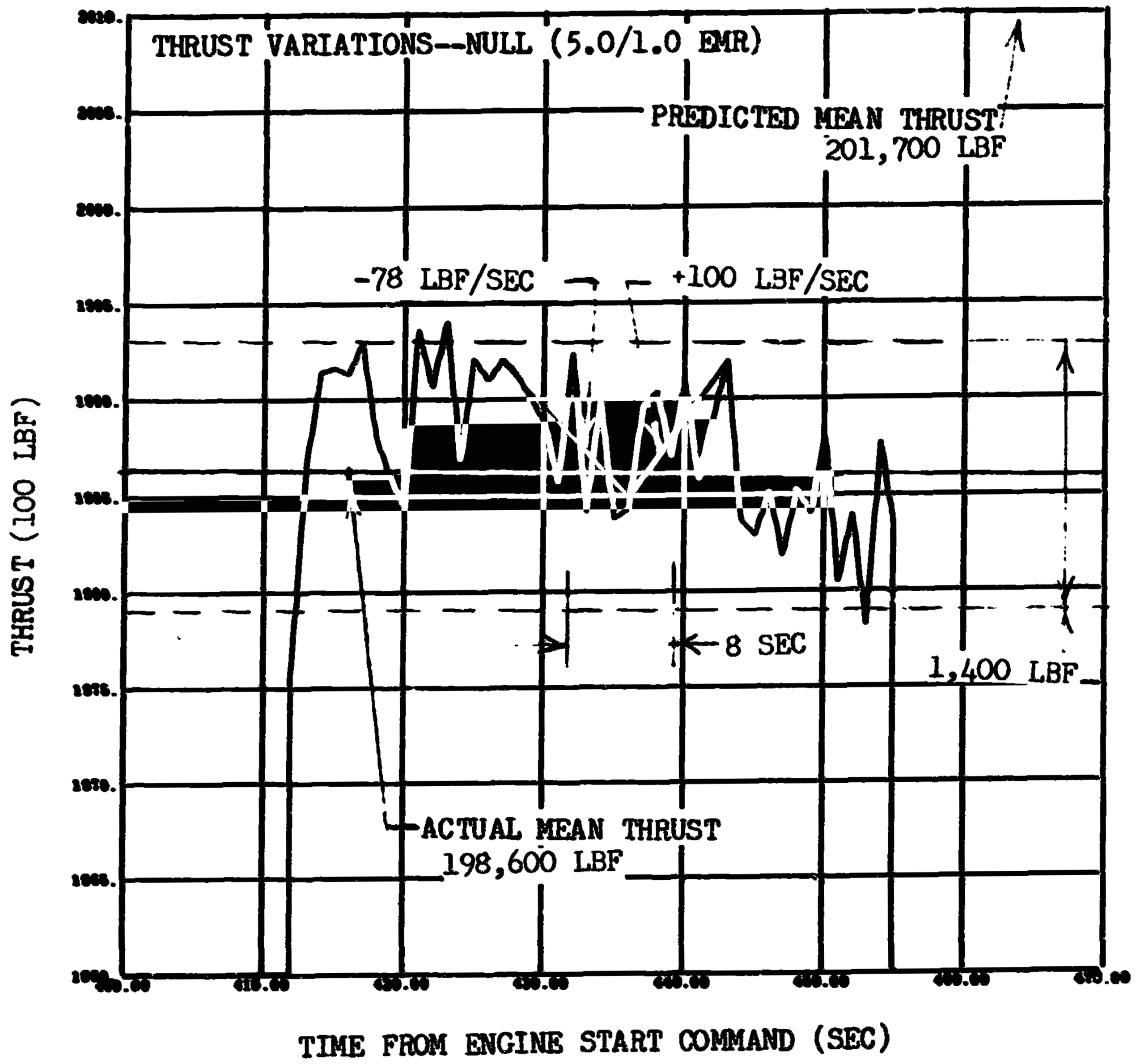


Figure 6-17. Thrust Variation (Sheet 4 of 4)

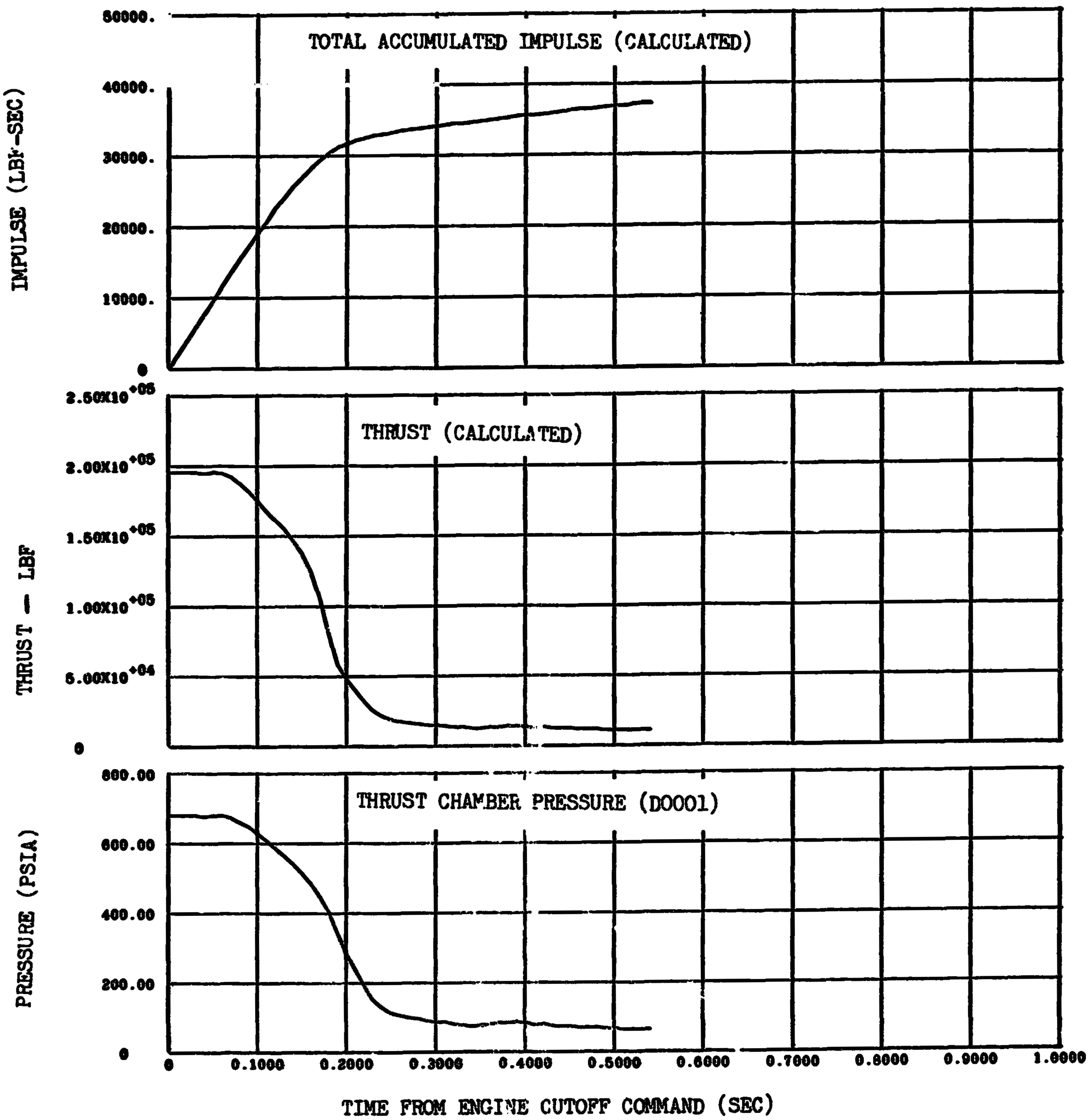


Figure 6-18. Engine Cutoff Transient Characteristics

EVENTS

IGNITION PHASE
- ENGINE START COMMAND P/U
- HELIUM CONTROL SOLENOID ENERGIZE P/U
- THRUST CHAMBER SPARK ON P/U
- GAS GENERATOR SPARK ON P/U
- IGNITION PHASE CONT SOLENOID ENERG P/U
- ASI LOX VALVE OPEN P/U
- LOX BLEED VALVE CLOSED P/U
- LH2 BLEED VALVE CLOSED P/U
- MAIN FUEL VALVE CLOSED D/O
- MAIN FUEL VALVE OPEN P/U
- ENGINE START COMMAND D/O

PUMP SPIN PHASE
- START TANK DISCH CONT SOLENOID ENERG P/U
- START TANK DISCHARGE VALVE CLOSED D/O
- START TANK DISCHARGE VALVE OPEN P/U

MAINSTAGE PHASE
- MAINSTAGE CONTROL SOLENOID ENERGIZE P/U
- START TANK DISCH CONT SOLENOID ENERG D/O
- MAIN LOX VALVE CLOSED D/O
- GAS GENERATOR VALVE CLOSED D/O
- START TANK DISCHARGE VALVE OPEN D/O
- GAS GENERATOR VALVE OPEN P/U
- LOX TURBINE BYPASS VALVE OPEN D/O
- START TANK DISCHARGE VALVE CLOSED P/U
- LOX TURBINE BYPASS VALVE CLOSED P/U
- MAINSTAGE PRESS. SWITCH NO. 1 PRESS. P/U
- MAINSTAGE PRESS. SWITCH NO. 2 PRESS. P/U
- MAIN LOX VALVE OPEN P/U
- THRUST CHAMBER SPARK ON D/O
- GAS GENERATOR SPARK ON D/O

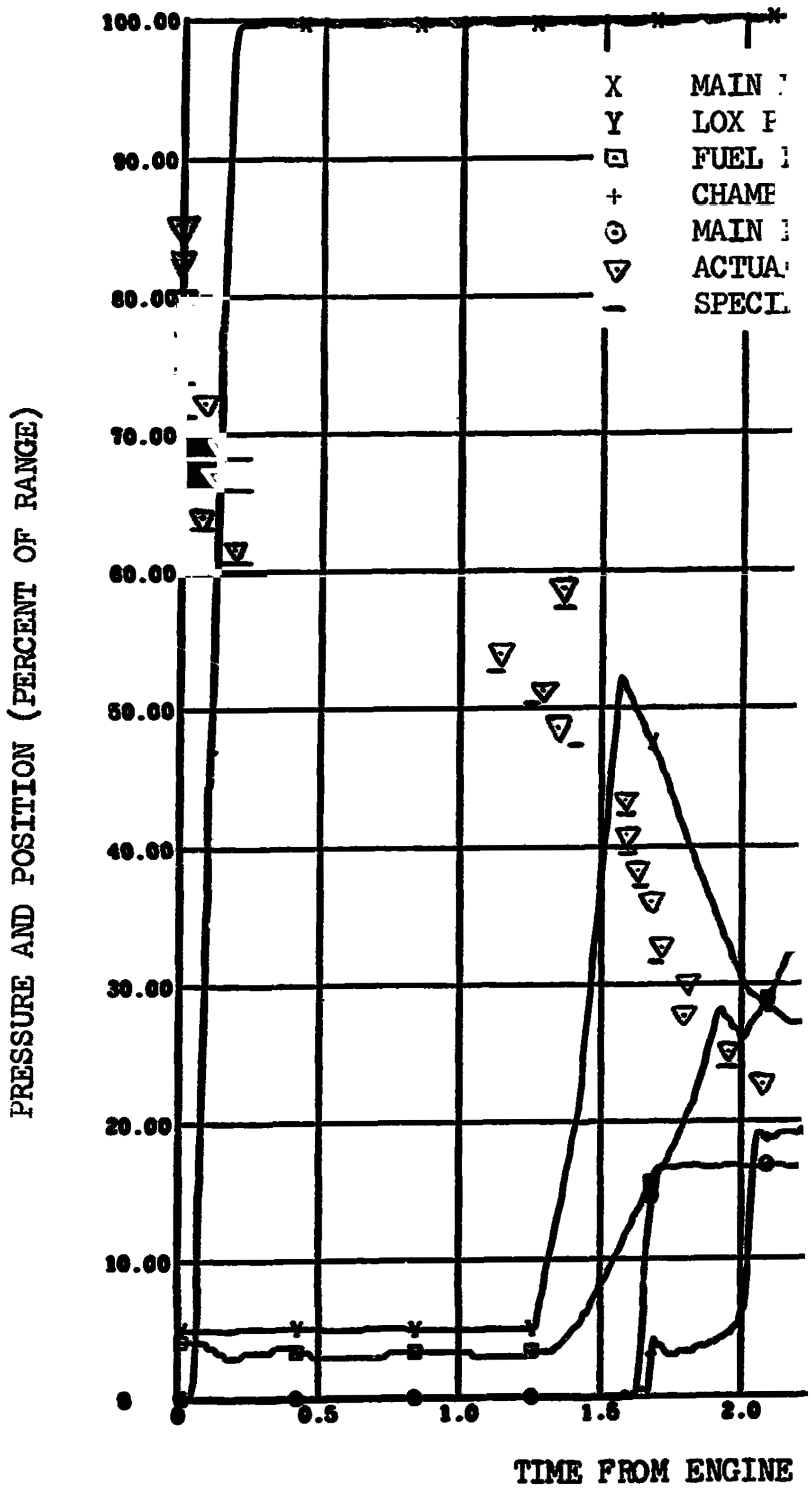


FIGURE 6-19. ENGINE

FOLDOUT FRAME 1

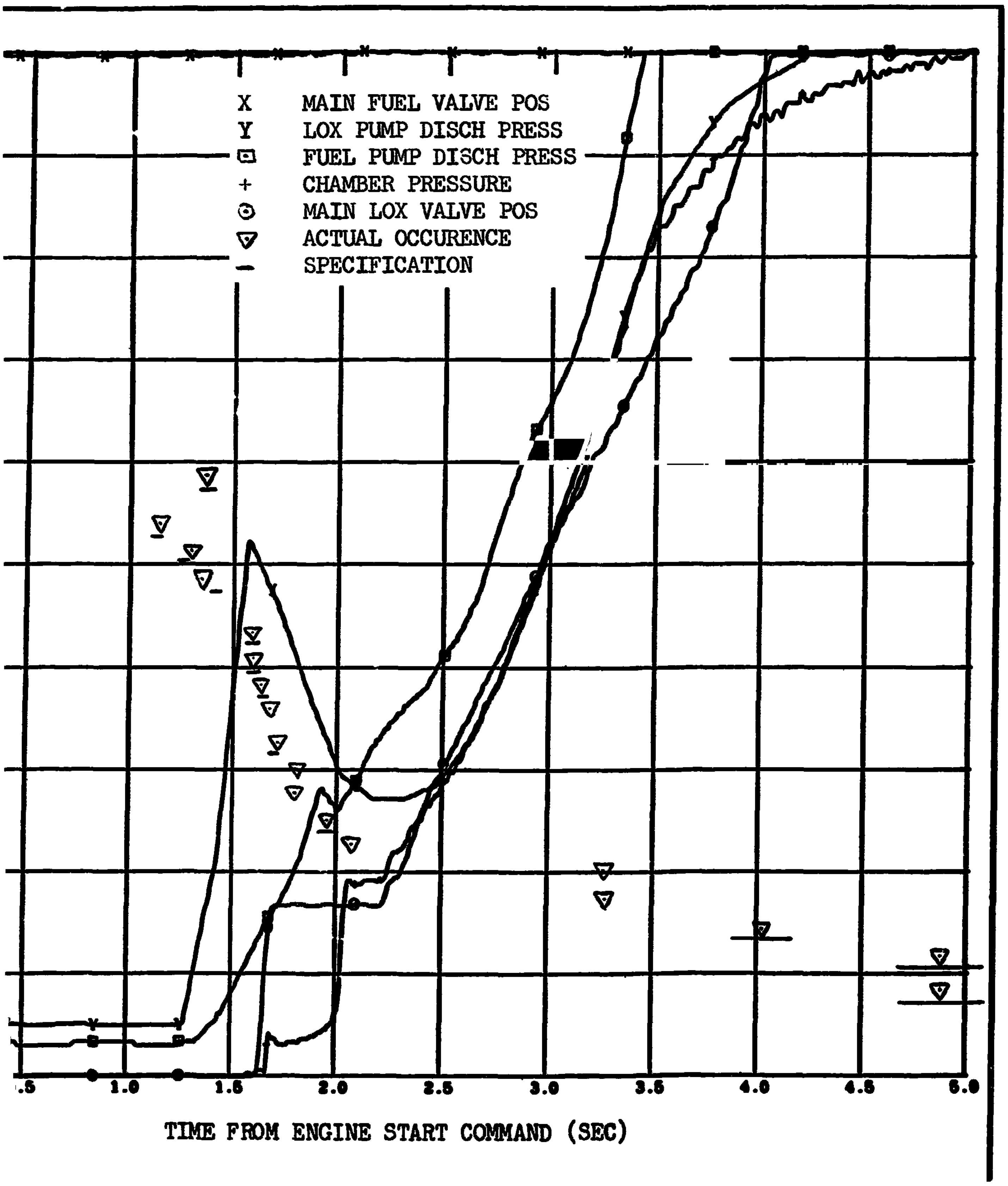


FIGURE 6-19. ENGINE START SEQUENCE

FOLDOUT FRAME 2

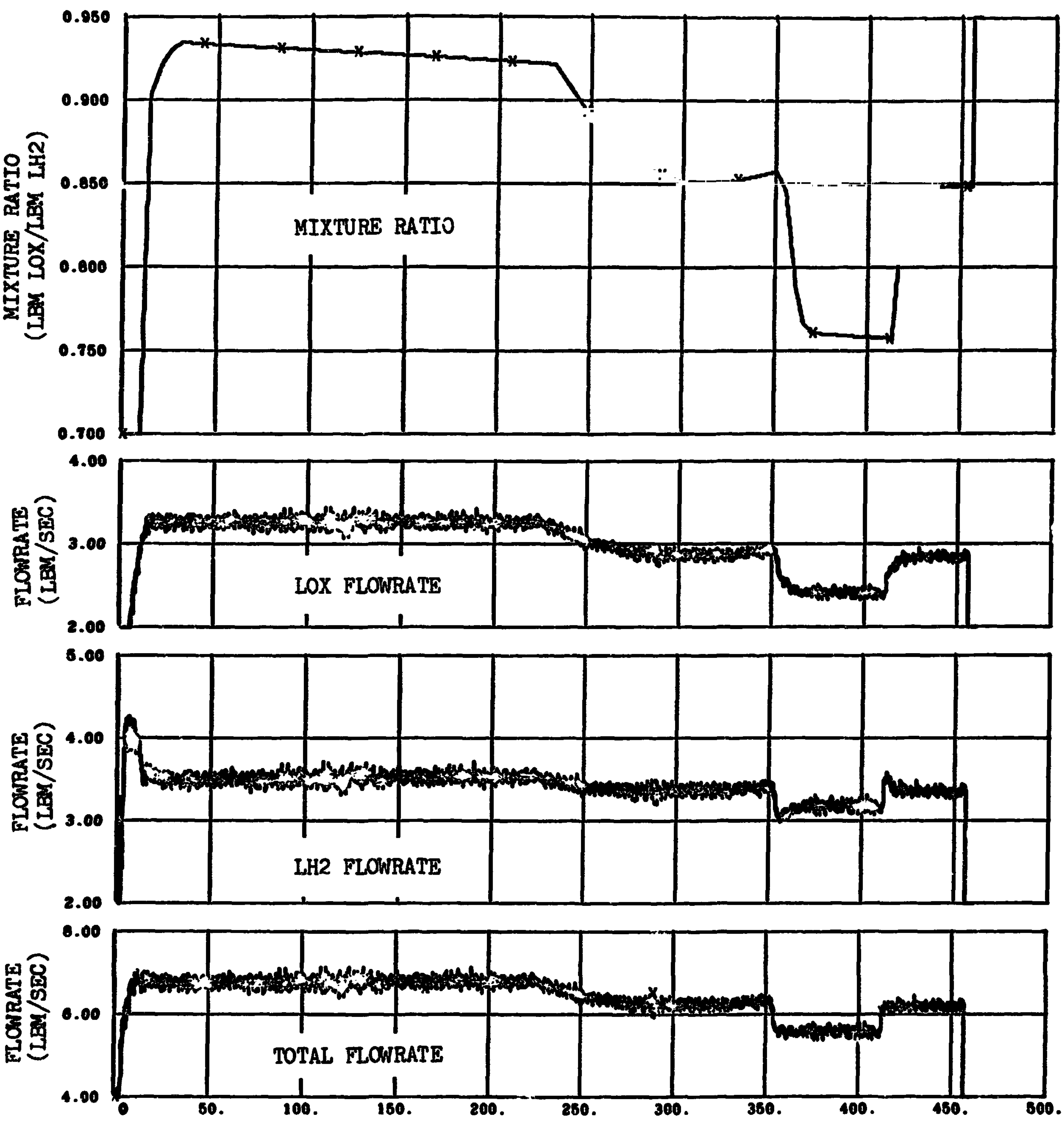


Figure 6-20. Gas Generator Performance

7. OXIDIZER SYSTEM

The oxidizer system functioned adequately, supplying LOX to the engine pump inlet within the specified limits. The net positive suction pressure (NPSP) available at the LOX pump inlet exceeded the engine manufacturer's minimum requirement at all times.

7.1 Pressurization Control

The LOX tank pressurization system (figure 3-1) satisfactorily maintained pressure in the LOX tank throughout the acceptance firing, and all portions of the system performed within the design requirements.

7.1.1 Prepressurization

LOX tank prepressurization and the two pressure makeup cycles before simulated liftoff (SLO) were accomplished from the ground support equipment (GSE) cold helium supply (figure 7-1). Subsequent to this, the LOX tank pressure increased from 39.5 to 41.7 psia due to an ullage volume decrease (caused by the common bulkhead depression and stage geometric changes that occur during LH2 tank prepressurization) and to the helium purges of the vent valve and the LOX tank ullage pressure sensing line.

In the course of simulated boost, the ullage pressure decayed to 38.6 psia causing a cold helium-sphere-supplied makeup cycle. This pressure decay was caused by cooling ullage gas which resulted from heat transfer with the colder common bulkhead.

Significant LOX tank prepressurization data are compared with that from two previous acceptance firings in table 7-1.

7.1.2 Pressurization

The LOX tank pressurization system performance was satisfactory during engine operation (figure 7-2) and compared reasonably well with that from previous stages.

The cold helium shutoff valves were opened at ESC -2.7 seconds, increasing the ullage pressure from 38.4 psia to momentary relief at 43.1 psia by engine start command.

During the last 230 seconds of burn the regulation level displayed a slightly erratic nature. The level was steady but oscillations of long duration and approximately 10 psia amplitude occurred. Slight overcompensation of the regulator appears to be the reason for this behavior. No corrective action appears necessary at this time.

Following enablement of the heat exchanger control valve, at ESC +21 sec, overcontrol flow was required 10 times to maintain the ullage pressure within the range of 38.4 to 39.7 psia during the firing. The number of overcontrol cycles was greater than usual due to the reduced range of the pressure control band.

The S-IVB-508 stage LOX tank pressurization system data are compared with that from the S-IVB-506N and 507 acceptance firings in table 7-2.

7.1.3 O2-H2 Burner Repressurization

LOX tank repressurization was performed during a test utilizing the O2-H2 burner and pressurant helium from the cold helium spheres. The tank was filled to a nominal second start level and prepressurized to 34.2 psia to simulate the burner inlet conditions expected during burner start and subsequent repressurization. The tank conditions are shown in figure 7-3; significant data are compared to that from previous firings in table 7-3. Data are also presented in section 10.

7.1.4 Ambient Repressurization

After burner repressurization, the ambient repressurization test was performed. The LOX tank was loaded to approximately 68 percent to simulate the load expected during orbital restart. The test data are presented in figure 7-4.

The ambient repressurization system performance during the S-IVB-509 acceptance test is compared with that during the 507 and 508 acceptance tests in table 7-3. The value for helium usage shown in this table includes the flow through the pilot bleed port of the helium shutoff valves. This pilot bleed flow, which amounts to about 6% of the total usage, is dumped overboard by venting directly from the ambient repressurization module.

7.2 Cold Helium Supply

The cold helium spheres were the source of the pressurant for both propellant tanks during O2-H2 burner operation and for the LOX tank during J-2 engine operation.

The system performance during the O2-H2 burner firing is discussed in paragraph 10.4.

During J-2 engine operation, demands on the cold helium system were normal and adequately met. The sphere pressure (2,775 psia) at engine start command was well within the start requirement of 2,600 $\pm$600 psia. Since cold helium sphere pressure transducers (D0016 and D0248) were not on the stage, the cold helium manifold pressures (D0261 and D0263) were used for system evaluation. Data are presented in figure 7-5 and table 7-4.

7.3 J-2 Heat Exchanger

The J-2 heat exchanger functioned satisfactorily (figure 7-6). The heat exchanger pressures, temperatures, helium flowrates and heat input rate are consistent with past experience. The LOX vent inlet pressure and the LOX tank diffuser temperature were comparable to previous test data. Table 7-5 compares significant 509 acceptance data with that from two previous acceptance firings.

7.4 LOX Pump Childown

The LOX pump chilldown system performance was adequate. At engine start command, the NPSP at the LOX pump inlet was above the minimum 11.9 psi required at that time. The results of the chilldown performance calculations are presented in figures 7-7 and 7-8; significant chilldown system data are compared with 507 and 508 data in table 7-6.

The chilldown pump was started at SLO -289.3 seconds in order to simulate conditions during the flight countdown. The chilldown shutoff valve was left open until ESC +411 seconds.

For the calculation of heat input to the LOX chilldown system, the normal reference temperature for section 1 (tank to engine pump inlet) is the chilldown pump discharge temperature (C0163).

Since C0163 was not installed on 509, the LOX bulk temperature (C0040) was used with a bias for constructing the chilldown pump discharge temperature.

7.5 Engine LOX Supply

The LOX supply system (figure 3-1) delivered the necessary quantity of LOX to the engine pump inlet throughout the engine firing and maintained the pressure and temperature conditions within a range that provided a LOX pump NPSP above the minimum requirements. The data and the calculated performance are presented in figure 7-9 and are compared with that from two previous acceptance firings in table 7-7.

During engine operation, the LOX pump inlet pressure and temperature were near the predicted values. Both were plotted in the engine LOX pump operating region (figure 7-10) and showed that the LOX pump inlet conditions were satisfactory throughout engine operation.

In figure 7-11, the LOX pump inlet temperature is plotted against the mass remaining in the tank during engine operation and compared to the

507 and 508 acceptance firing data. The data used for comparison have been biased to the LOX pump inlet temperature observed at engine start command of the S-IVB-509 acceptance firing to correct for instrumentation error, differences in heating during pressurization, and other test-to-test variations.

TABLE 7-1

LOX TANK PREPRESSURIZATION DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
Prepressurization duration (sec)	11.2	10.4	13.1
Number of cycles before SLO	2	1	2
Number of cycles after SLO	1	0	2
Prepressurization helium			
Average flowrate (lbm/sec)	0.31	0.35	0.31
Mass added to LOX tank during prepressurization* (lbm)	3.5	3.65	4.11
Mass added to LOX tank during makeup cycles before SLO (lbm)	1.2	1.0	2.0
Mass added to LOX tank during makeup cycles after SLO (lbm)	0.27	0	1.16
Ullage pressure			
At prepressurization initiation (psia)	14.8	14.8	15.1
At prepressurization termination (psia)	40.8	41.1	41.0
At engine start command (psia)	43.1	42.0	42.6
Events (sec from SLO)			
Prepressurization initiation	-164.241	-163.76	-163.88
Prepressurization termination	-153.00	-153.41	-150.83
Engine start command	510.981	511.693	511.758

* Does not include any makeup cycles.

TABLE 7-2

LOX TANK PRESSURIZATION DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
Number of overcontrol cycles*	11	8	7
Pressure control band			
Minimum (psia)	38.4	38.3	38.2
Maximum (psia)	39.7	40.0	40.3
Ullage pressure			
At pressurization initiation (psia)	38.6	38.4	40.0
At engine start command (psia)	43.1	42.0	42.6
Minimum during start transient (psia)	38.4	38.3	38.3
At engine cutoff command (psia)	40.5	40.6	39.1
Pressurant helium			
Overcontrol flowrate (lbm/sec)	0.34 to 0.42	0.34 to 0.44	0.35 to 0.42
Undercontrol flowrate (lbm/sec)	0.23 to 0.30	0.25 to 0.32	0.24 to 0.31
Usage before engine start (lbm)	0.6	0.5	0.6
Usage after engine start (lbm)	142	151	141
Events (sec from engine start command)			
LOX flight pressurization initiated	-2.7	-2.4	-2.4
Pressure switch override disabled	21.0	21.0	21.0

* Includes programmed overcontrol cycle during start transient

TABLE 7-3

LOX TANK REPRESSURIZATION DATA

Parameter	S-IVB-509 Ambient	S-IVB-509 Burner	S-IVB-508 Ambient	S-IVB-508 Burner	S-IVB-507 Ambient	S-IVB-507 Burner
Repressurization duration (sec)	82	170	84	171*	75	151*
Number of makeup cycles	0	0	0	0	0	0
Repressurization helium						
Usage** (lbm)	8.92	4.4	9.2	3.6	9.7	3.8
Average flowrate (lbm/sec)	0.1024	0.026	0.109	0.021	0.129	0.0252
Orifice effective area*** (in.^{2})	0.00878	0.00565	0.00888	0.00568	0.00890	0.00566
Ullage pressure						
At repressurization initiation (psia)	31.8	34.2	31.6	34.5	31.7	33.7
At repressurization termination (psia)	39.8	37.2	40.0	37.9	40.4	36.5
Rise rate (psi/min)	5.85	1.06	6.00	1.19	6.36	1.11

* Does not include the lag in repressurization initiation following burner start command.

** These values include the flow through the pilot bleed ports of the helium shutoff valves. See paragraphs 7.1.4 and 10.5 for further information.

*** Does not inlude the pilot bleed orifice effective area (0.00054 in.^{2}).

TABLE 7-4

COLD HELIUM SUPPLY DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
Pressure			
Simulated liftoff (psia)	2,990	2,975	2,993
Engine start command (psia)	2,775	2,845	2,838
Engine cutoff command (psia)	960	1,000	1,050
Average temperature			
Simulated liftoff (deg R)	40.5	40.0	41.2
Engine start command (deg R)	40.3	39.3	41.0
Engine cutoff command (deg R)	43.0	44.1	44.0
Helium mass			
Engine start command (lbm)	363	367	368
Engine cutoff command (lbm)	206	208	216
Helium consumption			
Calculated from sphere conditions (lbm)	157	159	152
Calculated from flowrate integration (lbm)	142	151	141

TABLE 7-5

J-2 HEAT EXCHANGER DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
Flowrate through heat exchanger			
During overcontrol (lbm/sec)	0.20	0.21	0.20
During undercontrol (lbm/sec)	0.09	0.093	0.09
Heat exchanger outlet temperature			
At end of 50-sec transient (deg R)	897	870	930
During overcontrol (deg R)	920	880	950
During undercontrol (deg R)	940	910	970
At engine cutoff command (deg R)	880	860	950
Heat exchanger outlet pressure			
During overcontrol (psia)	321	340	340
During undercontrol (psia)	383	395	395
Average LOX vent inlet pressure			
During overcontrol (psia)	62	62	63
During undercontrol (psia)	48	48	49

TABLE 7-6

LOX CHILLDOWN SYSTEM PERFORMANCE DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
NPSP			
At engine start command (psi)	35.7	32.8	33.8
Minimum required at start (psi)	11.9	11.9	11.9
At opening of prevalve (psi)	32.4	33.9	40.0
Pump inlet conditions			
Pressure at engine start command (psia)	50.7	51.0	51.1
Temperature at engine start command (deg R)	164.9	164.7	165.1
Average flow coefficient (sec^2/in^2ft^3)	17.1	17.5	17.2
Heat absorption rate (Btu/hr)			
Section 1 (tank to pump inlet)	4,800	7,000	10,500
Section 2 (pump inlet to bleed valve)	15,500	16,000	6,500
Section 3 (bleed valve to tank)	7,000	6,000	5,000
Total	26,000	29,000	22,000
Chilldown flowrate			
Unpressurized (gpm)	40.3	40.0	39.5
Pressurized (gpm)	42.3	42.9	41.2
Chilldown system pressure differential			
Unpressurized (gpm)	10.0	10.0	9.5
Pressurized (gpm)	10.7	11.1	10.4

Table 7-6 (Continued)

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
Events (sec from simulated liftoff)			
Chilldown initiation	-289.3	-288.7	-288.6
Prepressurization	-164.2	-163.7	-163.9
Prevalve open command	506.9	507.7	507.7
Prevalve closed signal dropout	507.7	508.5	508.7
Prevalve open signal pickup	509.1	509.8	510.4
Delay between prevalve open command and pickup of open signal	1.42	2.14	2.50
Engine start command	511.0	511.7	511.7
Chilldown shutoff valve closed	921.7	922.2	922.1

TABLE 7-7

LOX PUMP INLET CONDITION DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
Pump inlet conditions			
Static pressure at engine start command (psia)	50.7	51.0	51.1
Temperature at engine start command (deg R)	164.9	164.7	165.1
Temperature at engine cutoff command (deg R)	166.5	166.4	166.8
NPSP requirements at pump interface			
Minimum at engine start command (psi)	11.9	11.9	11.9
At high EMR (psi)	20.0	20.0	20.0
After EMR cutback (psi)	14.0	14.0	14.0
NPSP available at pump interface			
At engine start command (psi)	35.7	33.9	33.8
Maximum during firing (psi)	35.7	33.9	33.8
Time of maximum (sec from engine start command)	0	0	0
Minimum during firing (psi)	23.5	23.3	19.0
Time of minimum (sec from engine start command)	450	460	436
At engine cutoff command (psi)	23.6	23.3	19.0
LOX feed duct			
At high EMR			
Pressure drop (psi)	2.0	2.0	1.4
Flowrate (lbm/sec)	455	454	465
After EMR cutback			
Pressure drop (psi)	0.6	1.1	0.9
Flowrate (lbm/sec)	400	390	422

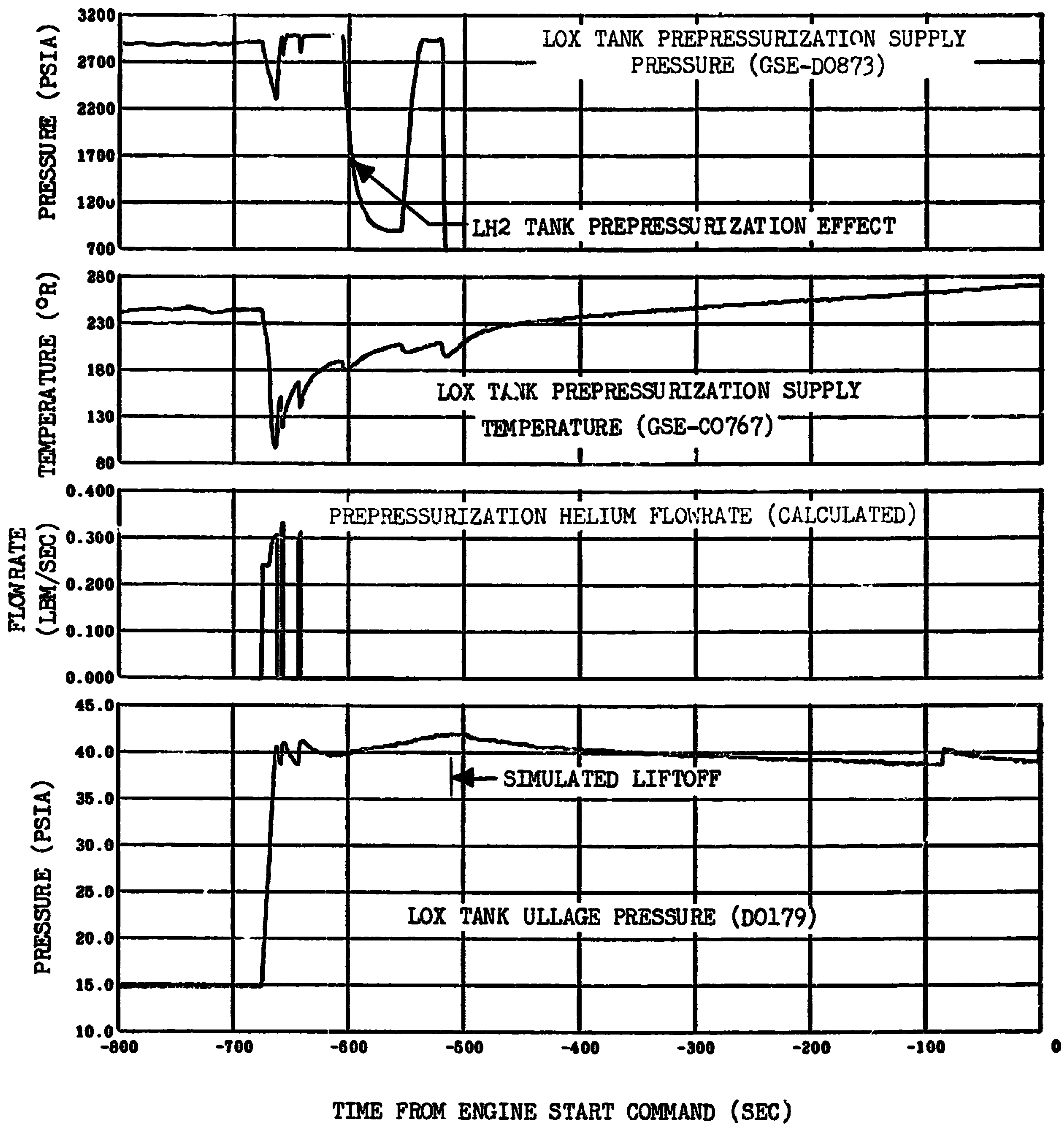


Figure 7-1. LOX Tank Prepressurization

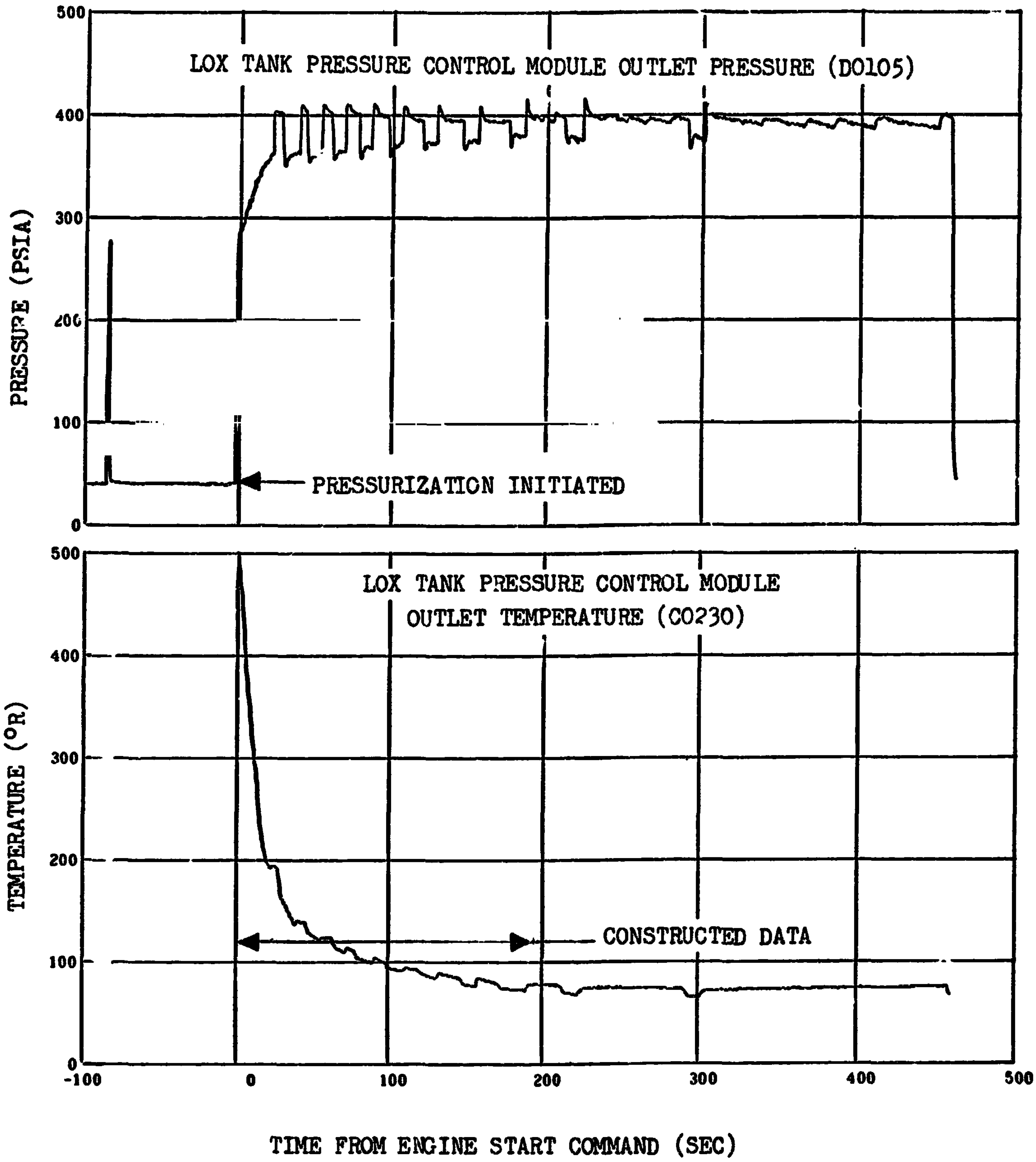


Figure 7-2. LOX Tank Pressurization System Performance (Sheet 1 of 2)

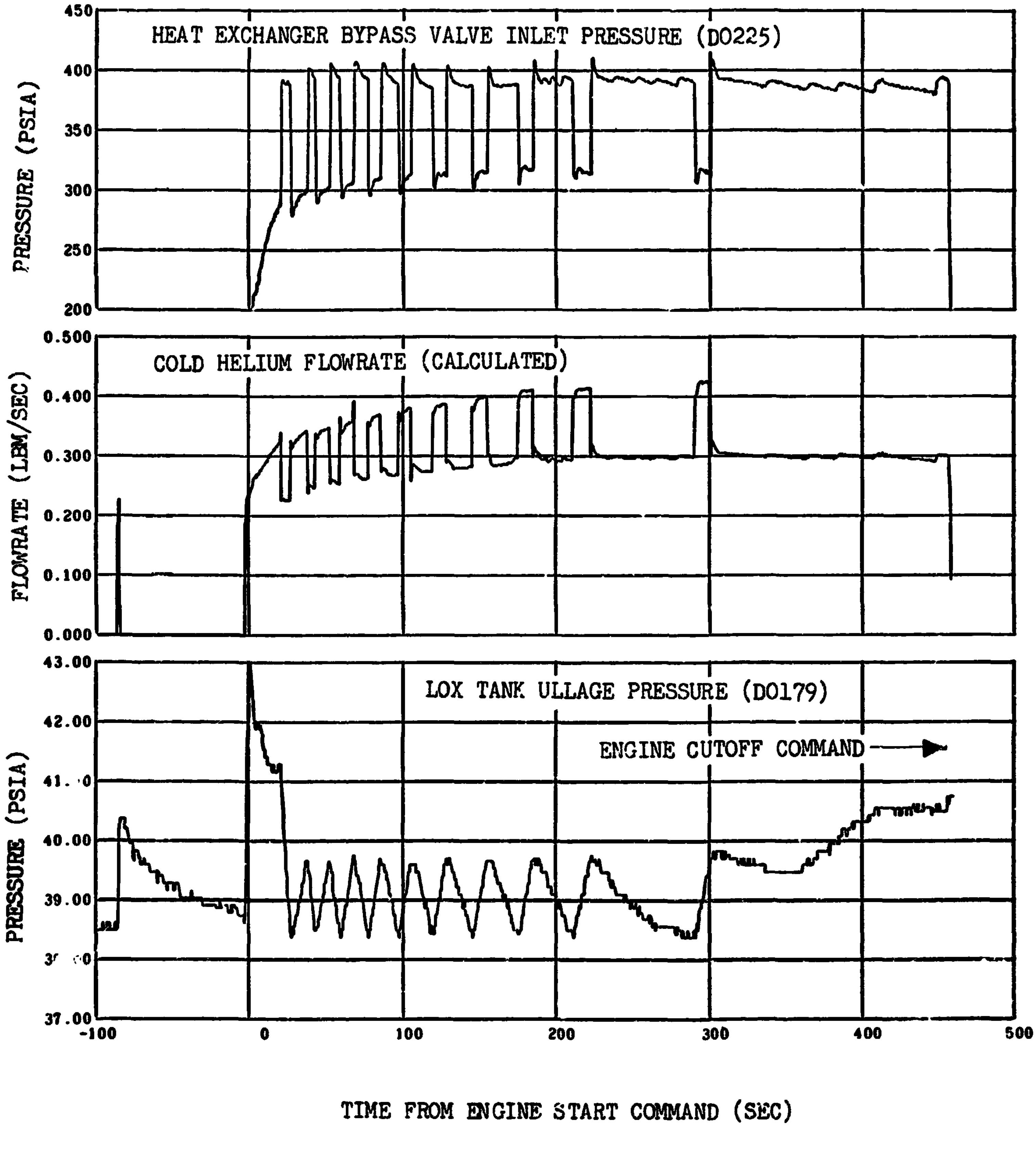


Figure 7-2. LOX Tank Pressurization System Performance (Sheet 2 of 2)

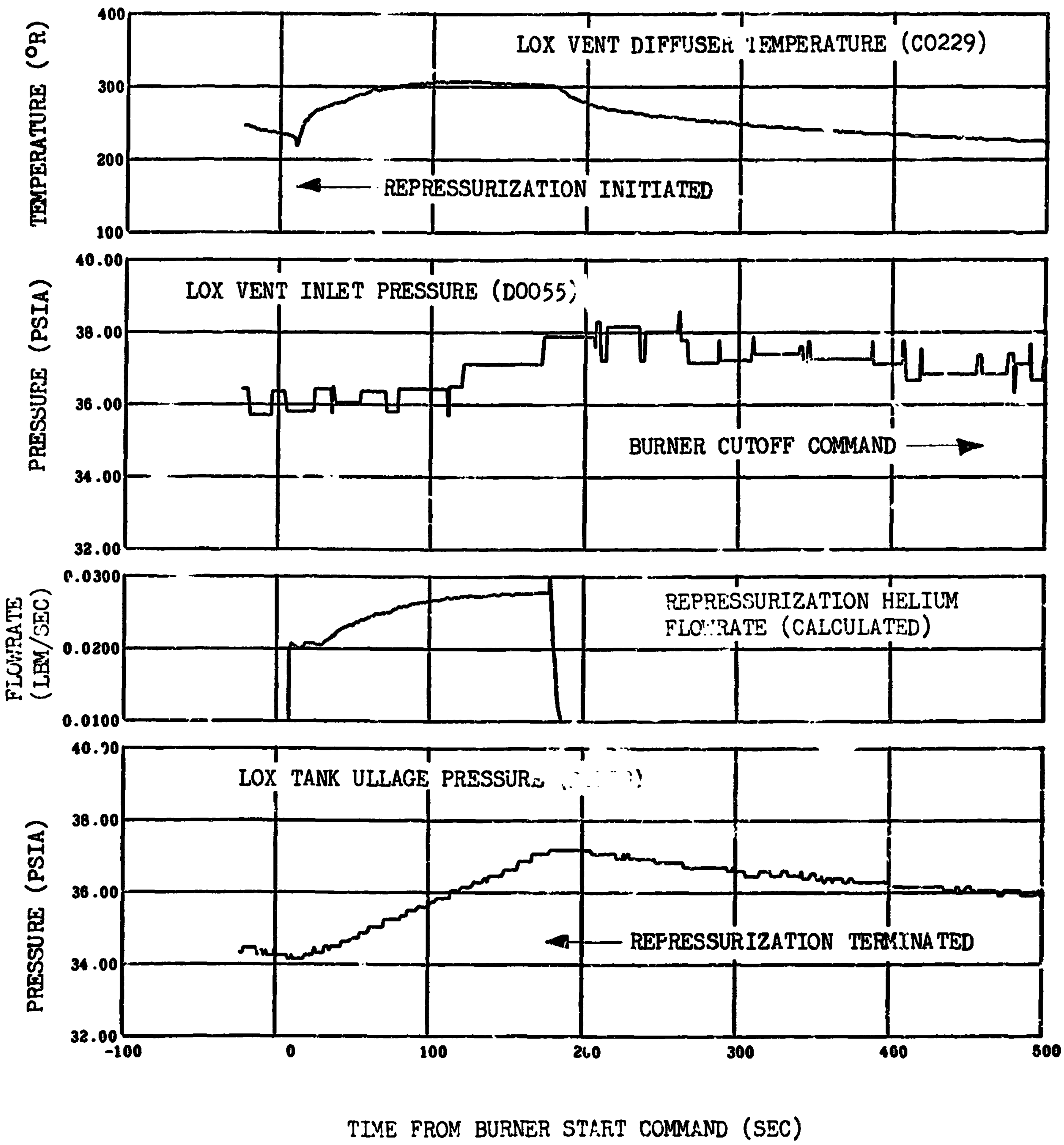


Figure 7-3. LOX Tank 02-H2 Burner Repressurization

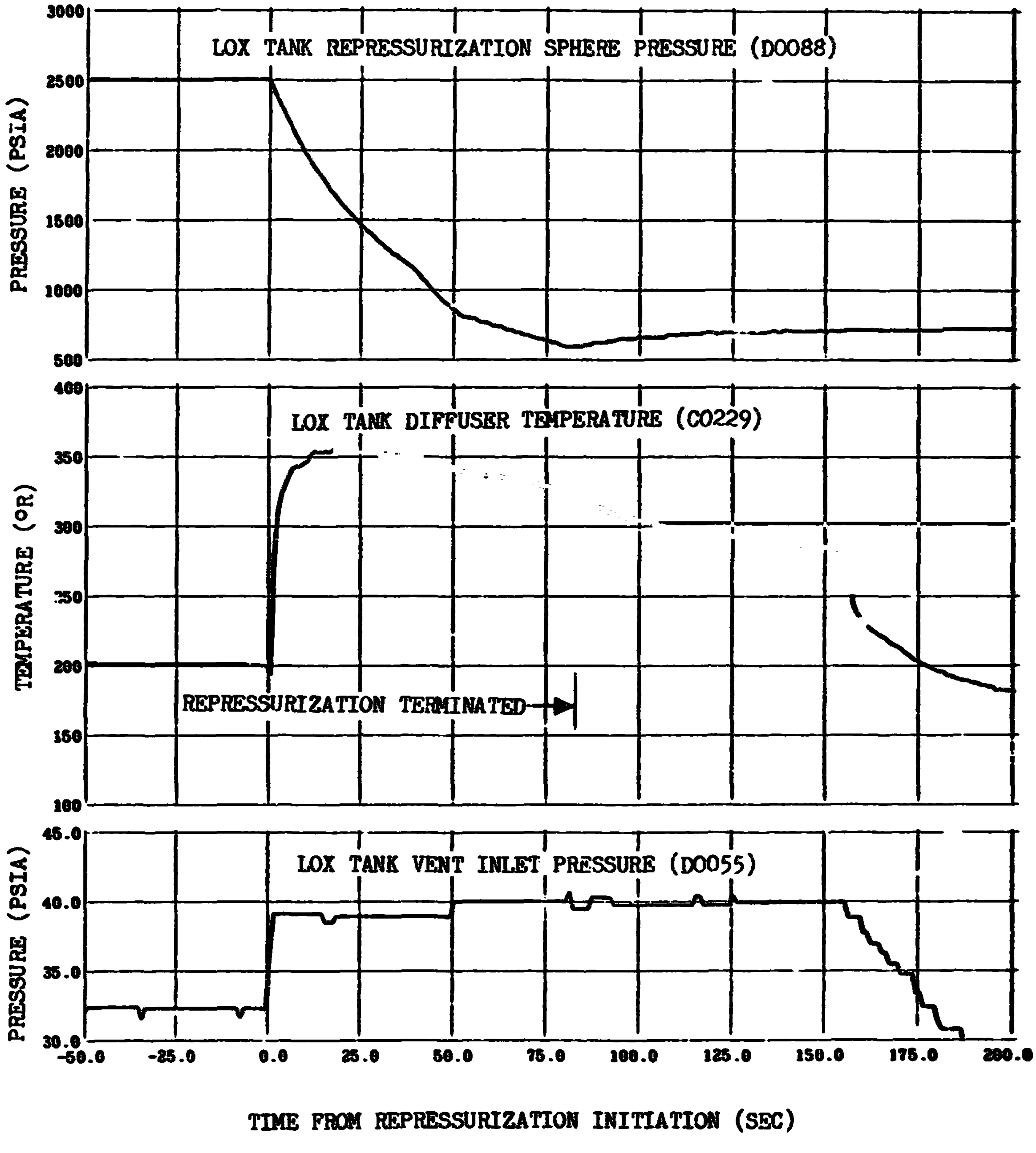


Figure 7-4. LOX Tank Ambient Helium Repressurization (Sheet 1 of 2)

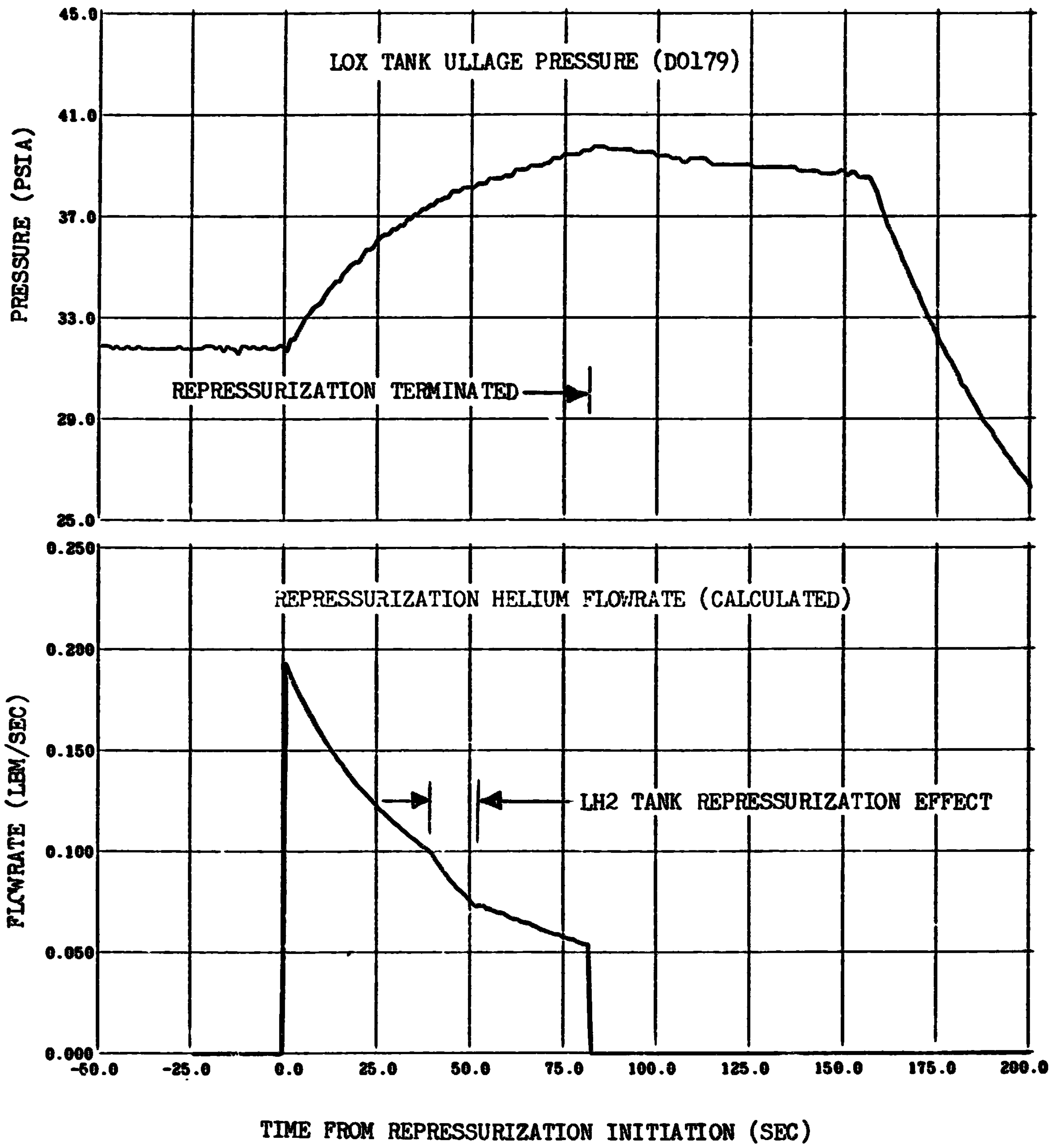


Figure 7-4. LOX Tank Ambient Helium Repressurization (Sheet 2 of 2)

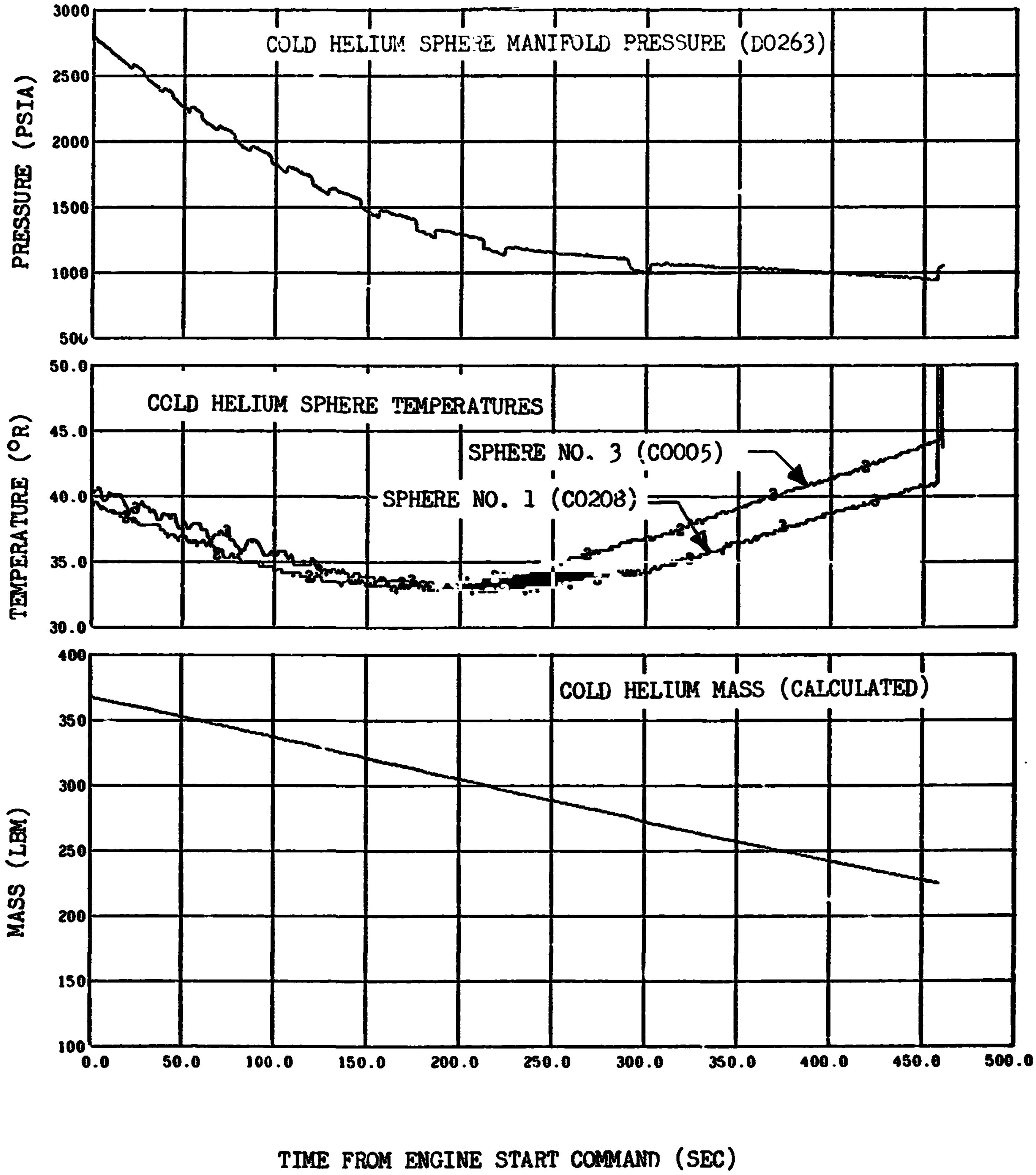


Figure 7-5. Cold Helium Supply

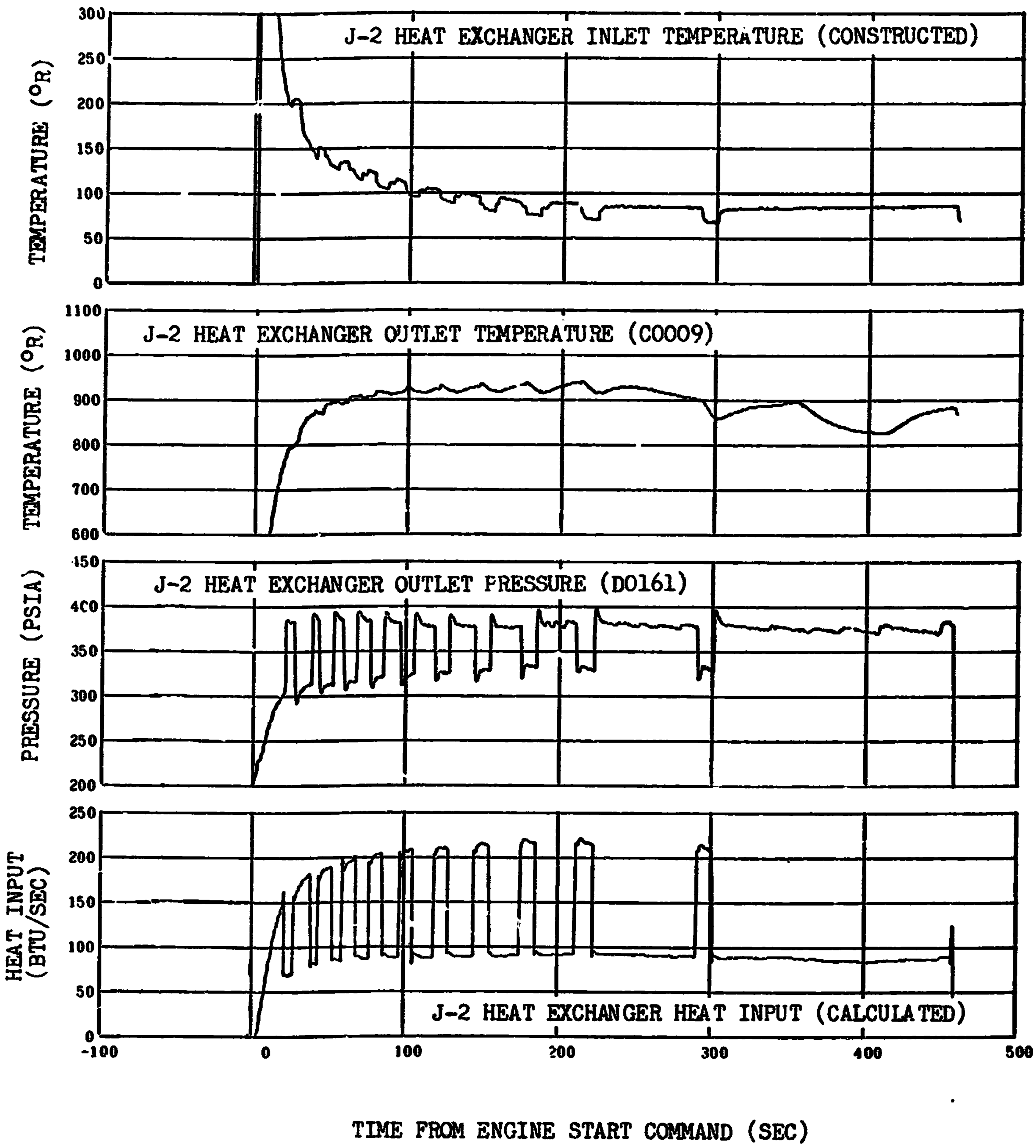


Figure 7-6. J-2 Heat Exchanger Performance (Sheet 1 of 2)

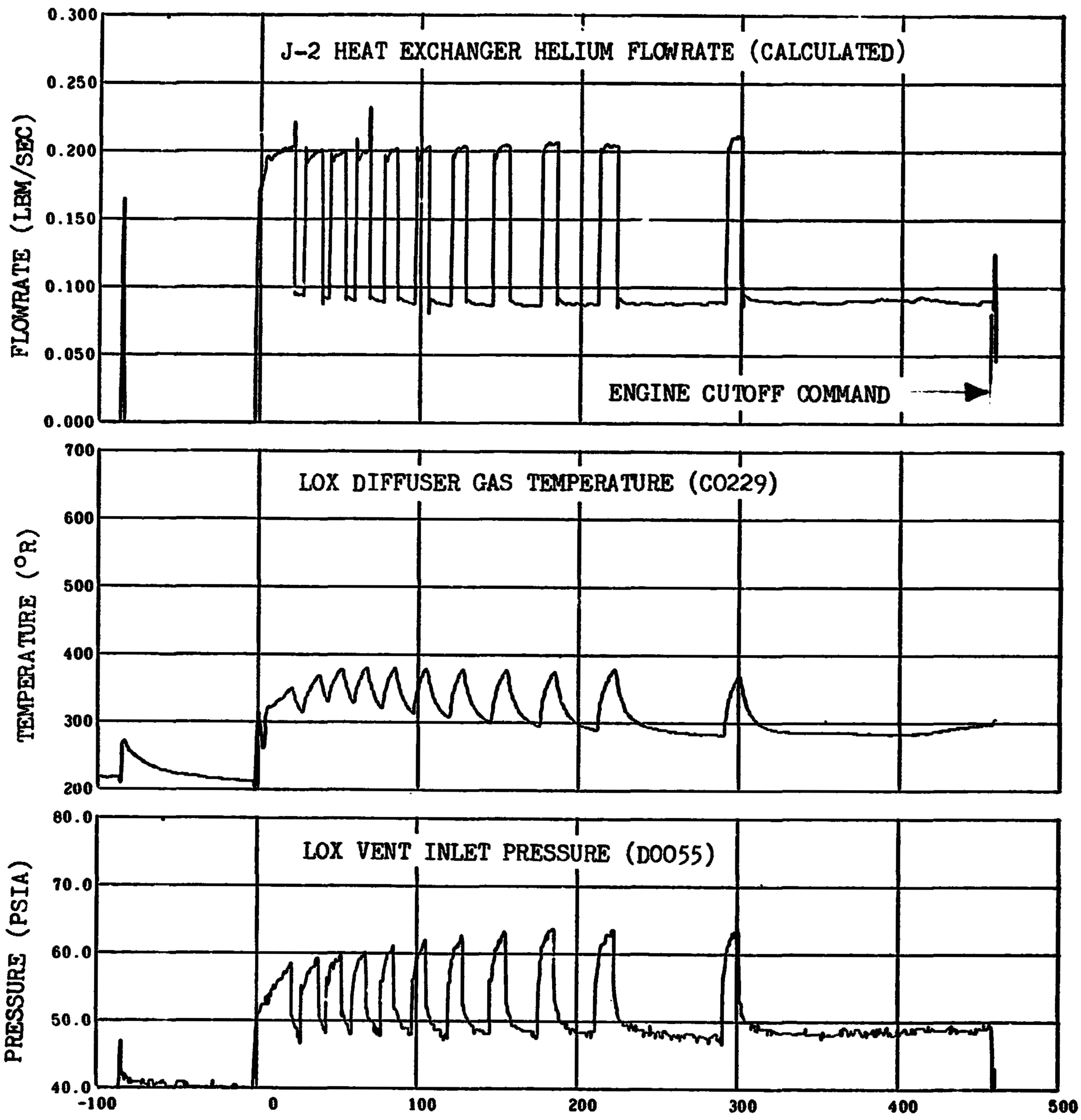


Figure 7-6. J-2 Heat Exchanger Performance (Sheet 2 of 2)

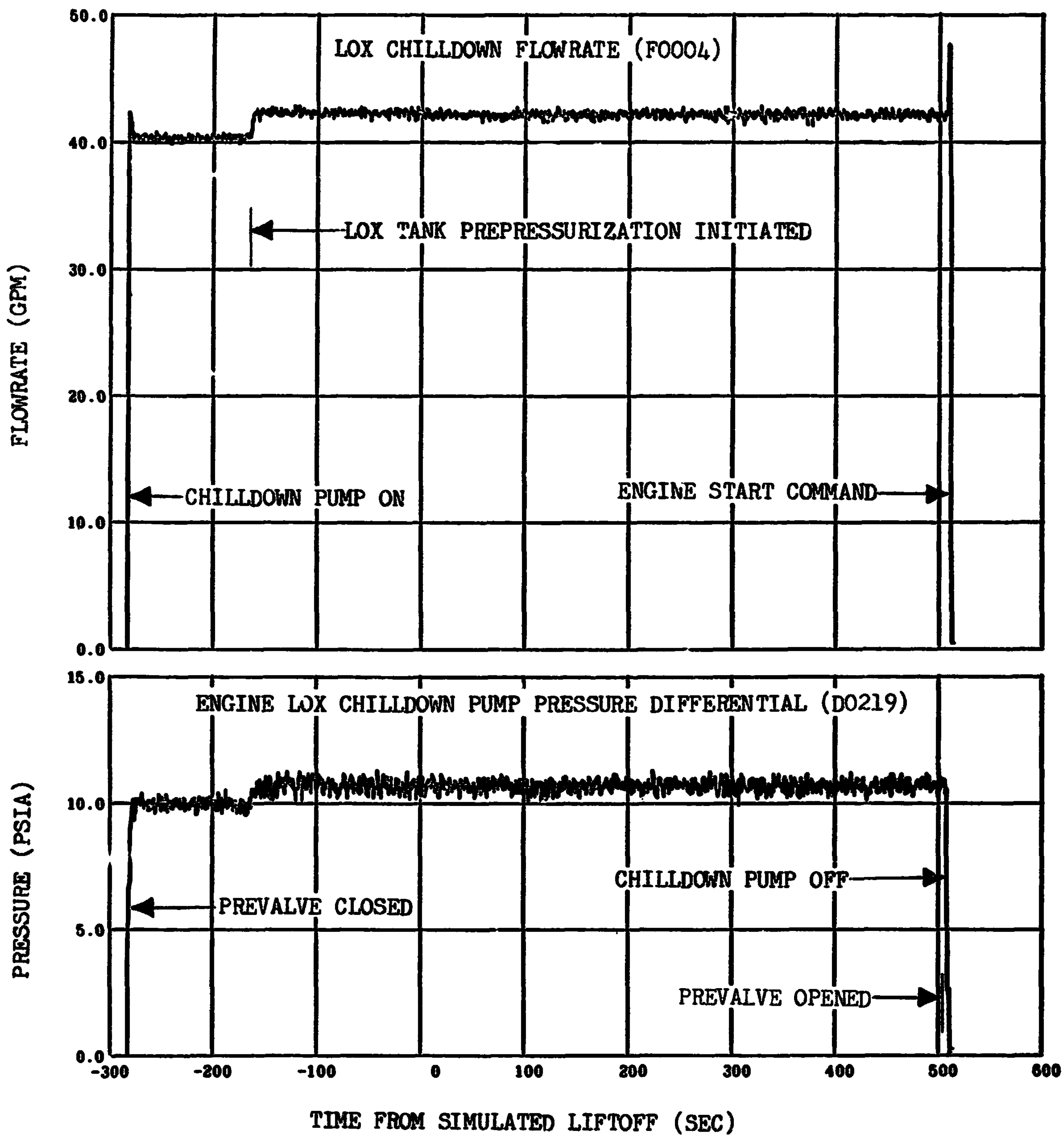


Figure 7-7. LOX Pump Chilldown (Sheet 1 of 3)

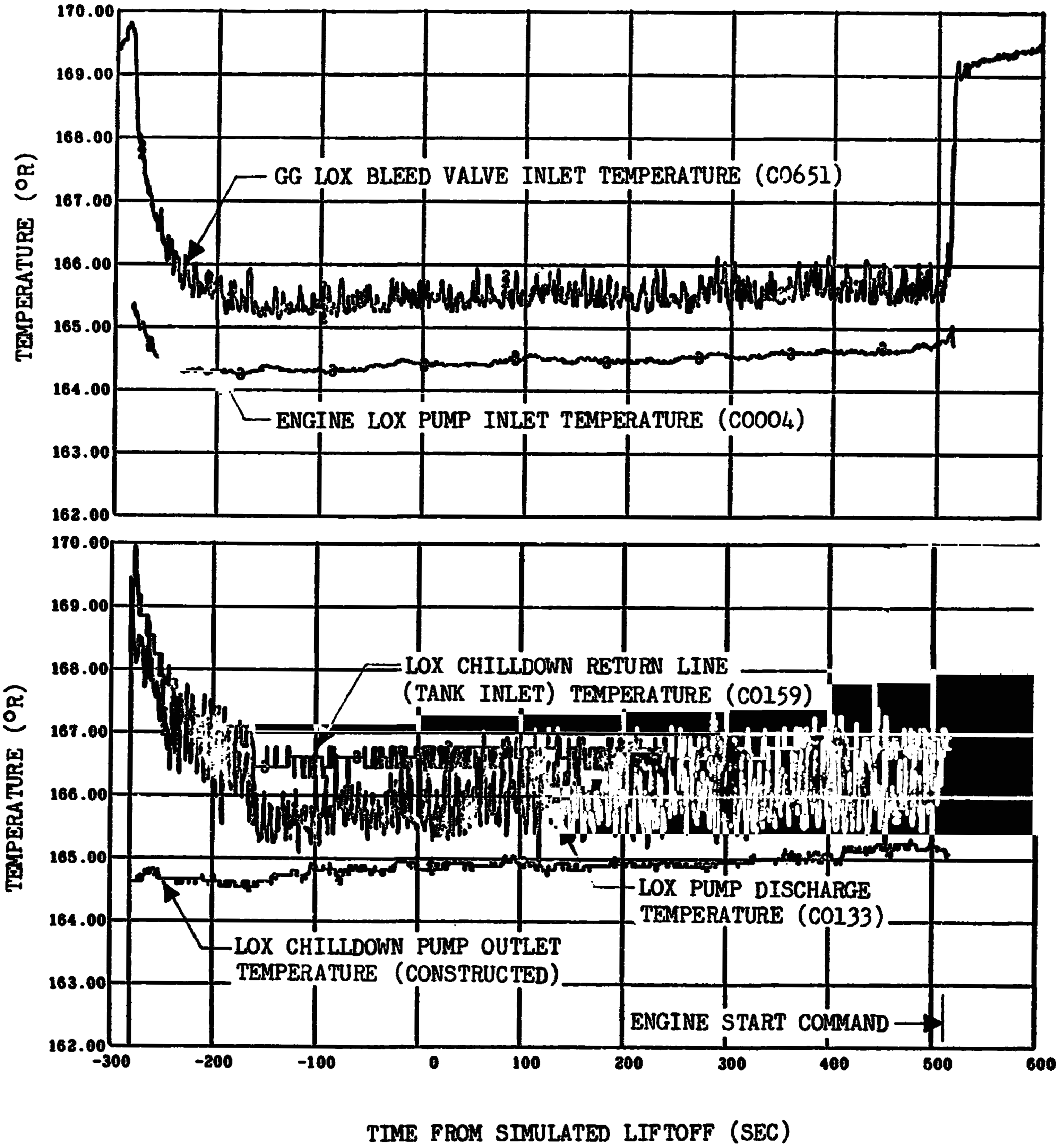


Figure 7-7. LOX Pump Chilldown (Sheet 2 of 3)

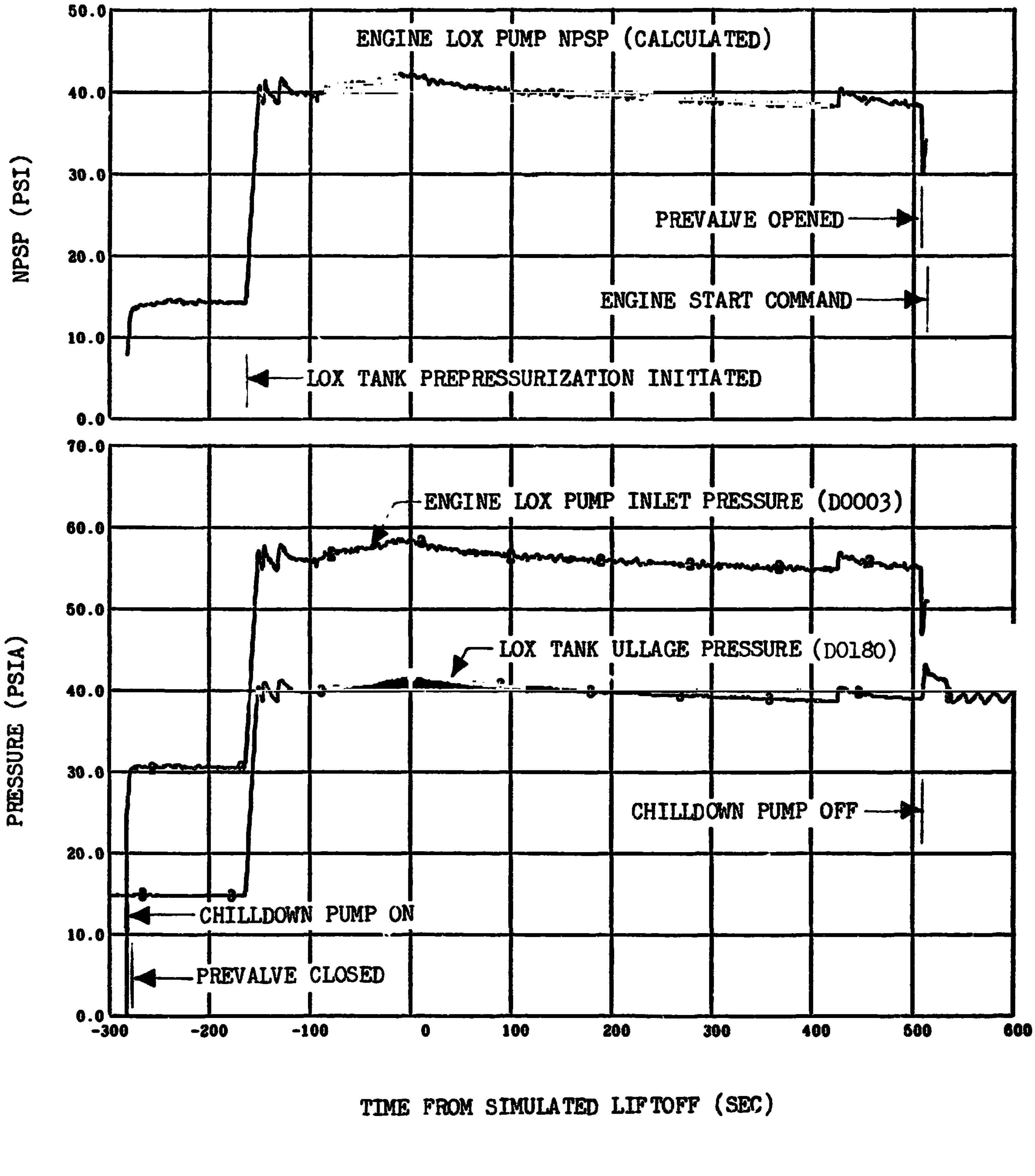


Figure 7-7. LOX Pump Chilldown (Sheet 3 of 3)

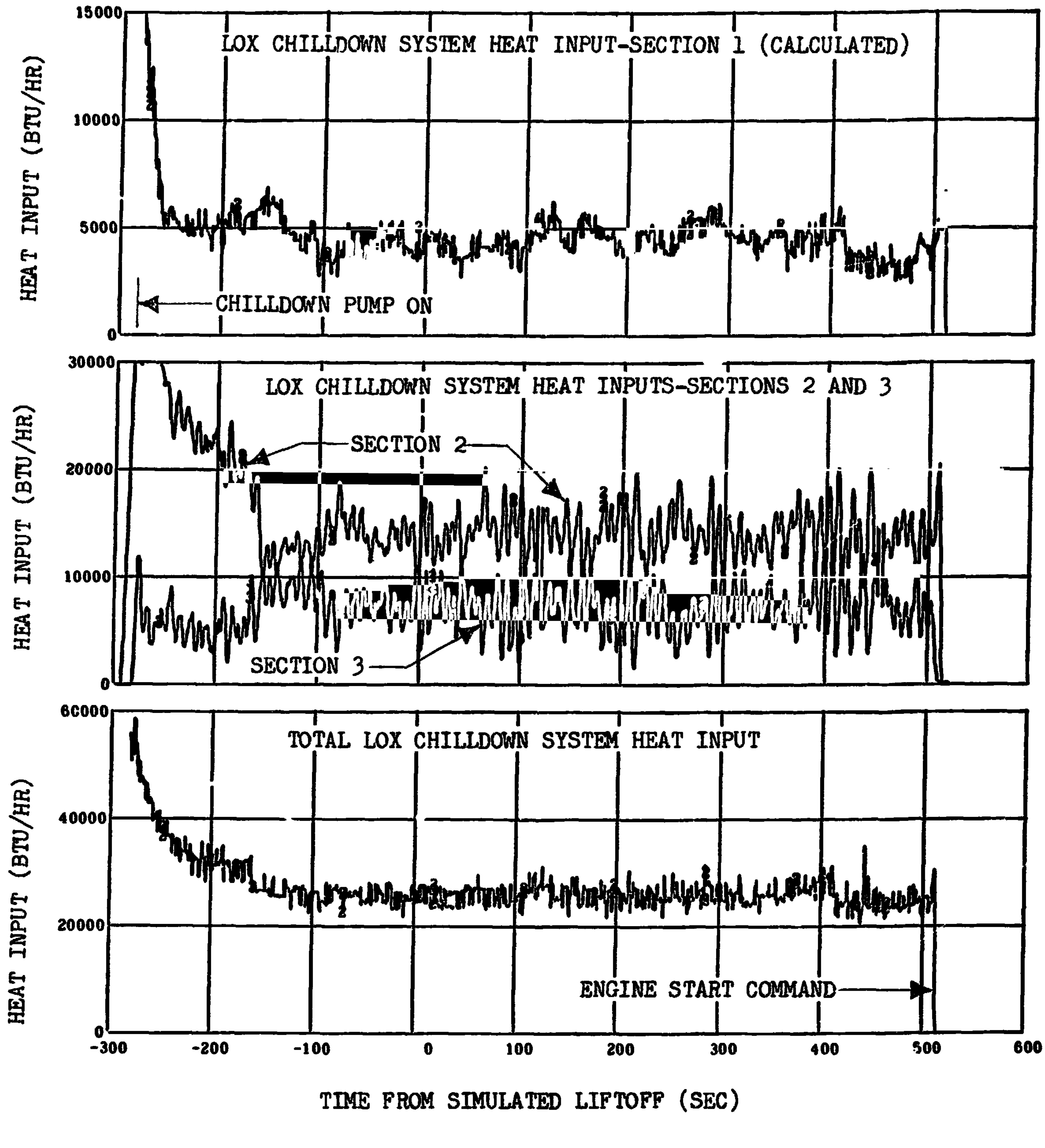


Figure 7-8. LOX Pump Chilldown Characteristics

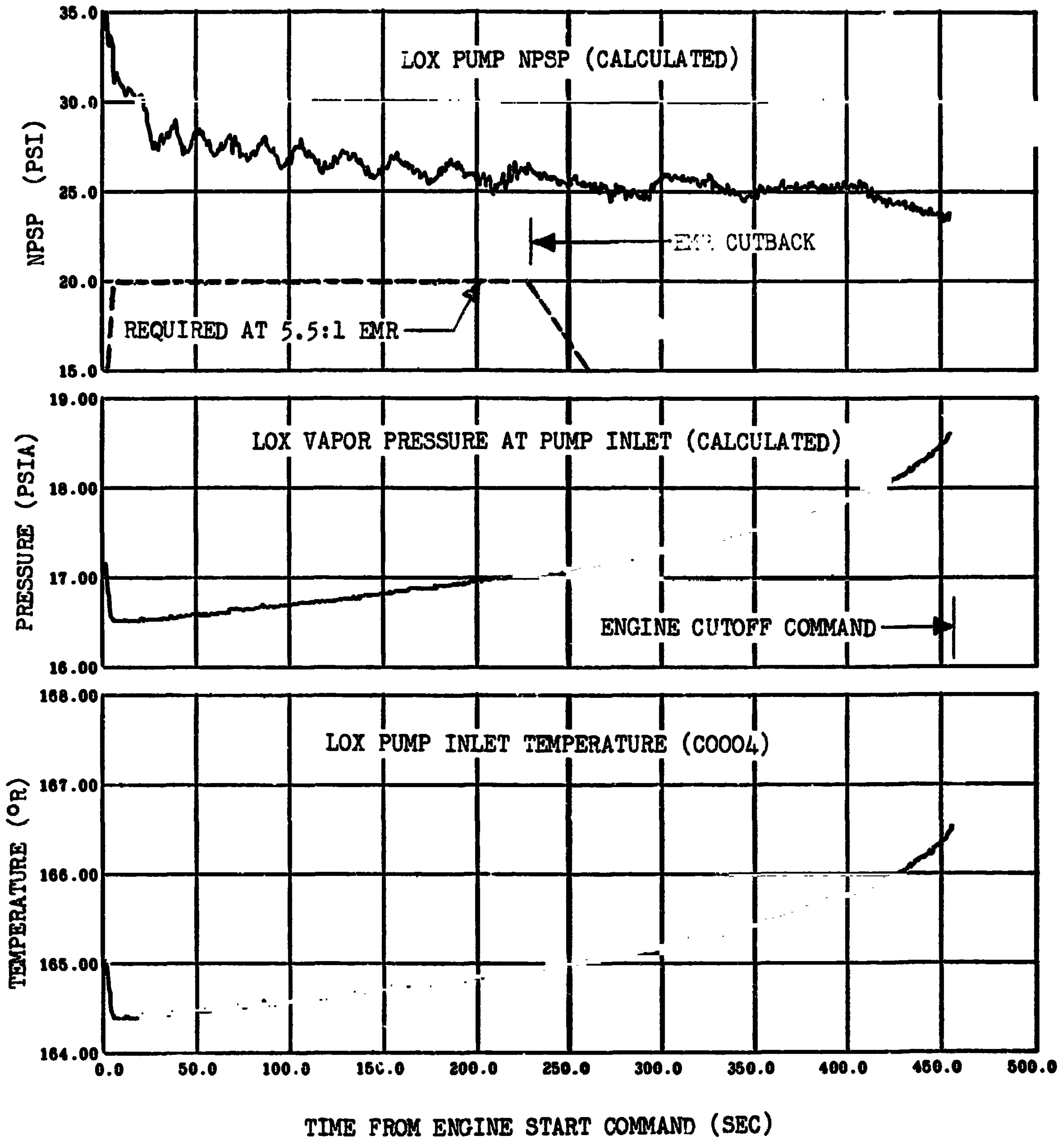


Figure 7-9. LOX Pump Inlet Conditions (Sheet 1 of 2)

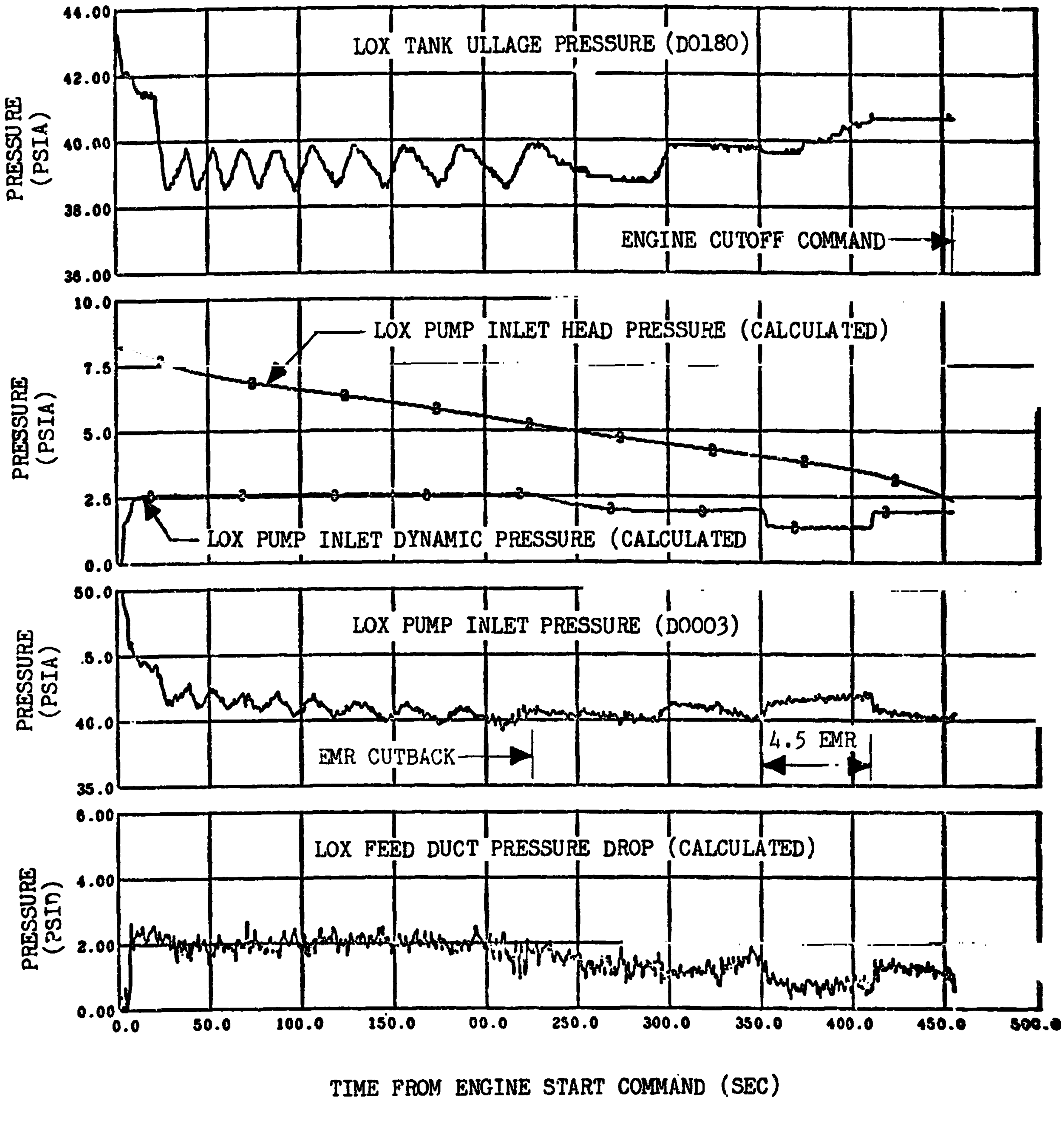


Figure 7-9. LOX Pump Inlet Conditions (Sheet 2 of 2)

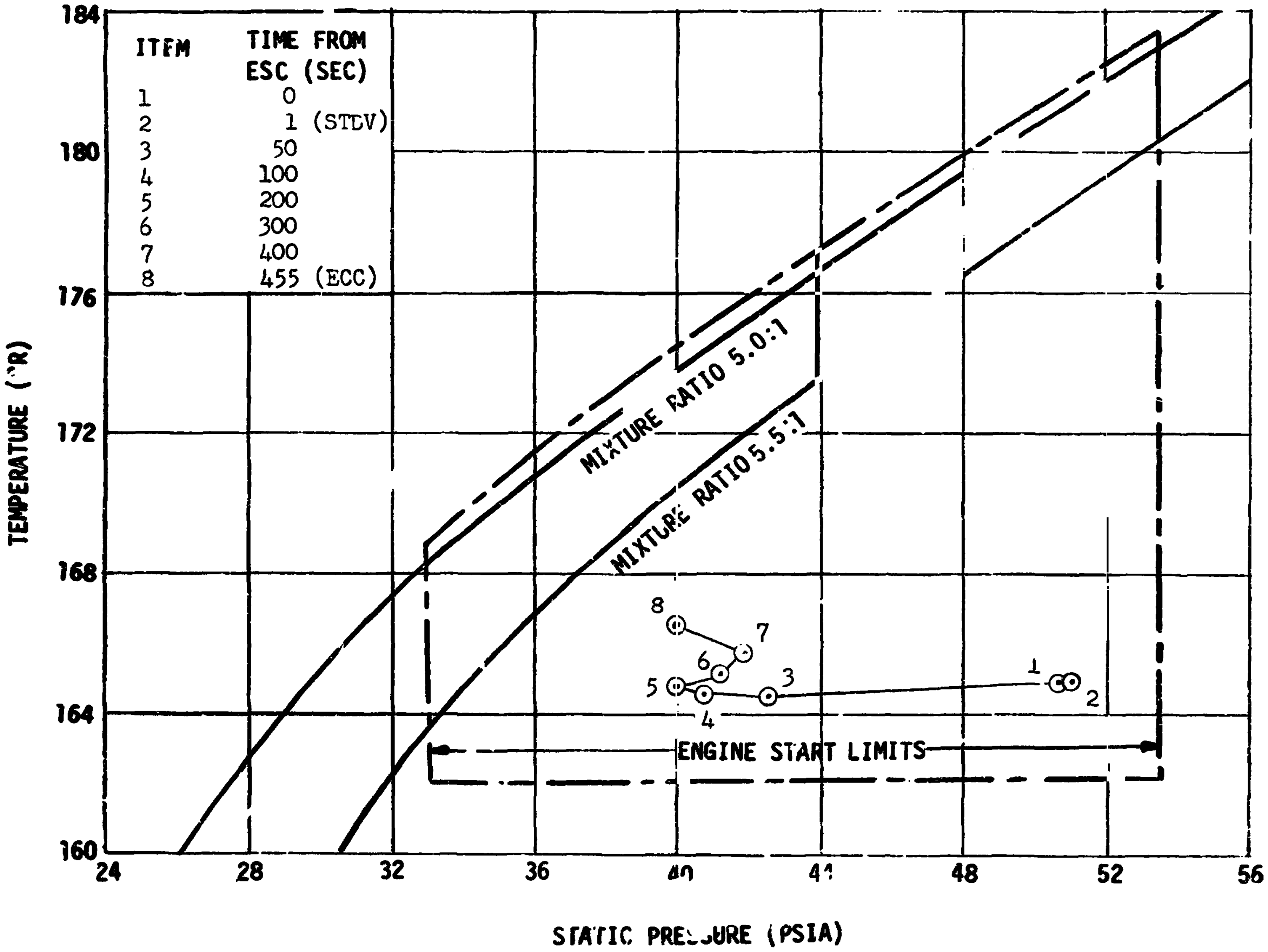


Figure 7-10. LOX Pump Inlet Conditions During Firing

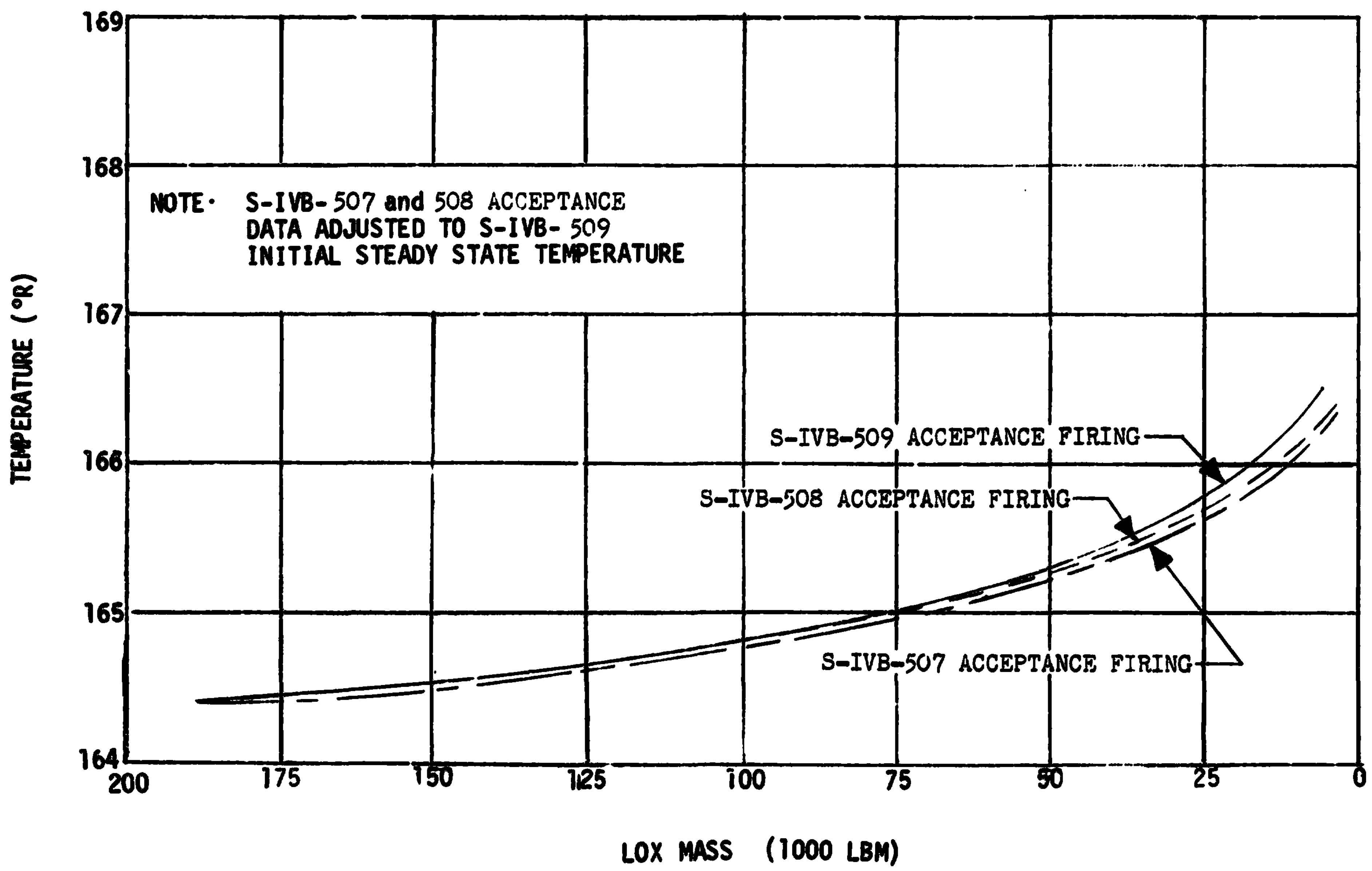


Figure 7-11. Effect of LOX Mass Level on LOX Pump Inlet Temperature

8. FUEL SYSTEM

The fuel system performed as expected and supplied LH2 to the engine within the limits defined in the engine specification.

8.1 Pressurization Control

The LH2 tank pressurization system (figure 3-1) adequately controlled LH2 tank ullage pressure during prepressurization, throughout the firing, and during the repressurization periods.

8.1.1 Prepressurization

The LH2 tank was satisfactorily prepressurized with helium from ground support equipment (GSE) console B. Figure 8-1 presents the prepressurization data; table 8-1 compares the S-IVB-509 data with that from 507 and 508 stages. The rate of prepressurization was substantially slower on 509 than on 507 and 508 because the supply pressure, measurement D0792, was significantly lower (figure 8-1). Prepressurization was terminated by actuation of the control pressure switch at SLO -43.1 seconds. After prepressurization, the ullage pressure increased because of ambient heating until it reached a level of 32.1 psia. At this point, the ullage pressure stabilized as a result of the relief action of the latching vent valve and remained essentially constant until engine start command.

8.1.2 Pressurization

During engine operation, the LH2 tank pressurization was satisfactorily accomplished by GH2 bleed from the J-2 engine (figure 3-1). The data are presented in figure 8-2 and compared with data from two previous acceptance firings in table 8-2.

In order to exercise all system components in both burn modes, control was transferred from the first burn pressurization mode to the second burn pressurization mode at ESC +350 seconds. Since the pressure switch range is the same for both modes (28 to 31 psia), system performance did not deviate because of the change to the second burn pressurization mode;

however, a programmed cutback of engine mixture ratio to 4.5:1, which also occurred at ESC +350 seconds, did affect certain performance parameters. To preclude the possibility of loss of NPSP near the end of the firing because of bulk heating, step pressurization was initiated at ESC +410 seconds. This was coincident with the EMR being returned to 5.0:1 and resulted in another significant change in pressurization system performance.

The LH2 tank ullage pressure was above the 30.4 psia pressure switch pickup level throughout the firing. Microswitch talkback indicated that the latching vent valve was partially open and venting from ESC +4 seconds to ESC +241 seconds and again subsequent to LH2 tank step pressurization during the period from ECC -37 seconds to ECC +36 seconds. Also, the vent and relief valve was partially open and venting from ECC -14 seconds to ECC +3 seconds.

8.1.3 O2-H2 Burner Repressurization

The O2-H2 burner was utilized for LH2 tank repressurization. For the test, the tank was filled to a nominal second start level. Burner start command was followed by a 6.89-second lag before the initiation of repressurization, in order to provide higher burner chamber pressure (and improved combustion stability) during the start transient. The LH2 tank conditions are shown in figure 8-3; significant data are compared to previous stage data in table 8-3. Additional, more detailed discussion is presented in section 10.

The LH2 tank ullage pressure rise rate was 21 percent higher than the theoretical rate of 3.25 psi/min that was based on a constant-Q burner, a constant helium flowrate, and an assumed constant burner helium inlet temperature of 40 deg R (the same reference conditions used for previous acceptance firing evaluations). During the S-IVB-509 burner operation, the actual total energy of the helium at the burner outlet to the LH2 tank was 29 percent higher than the theoretical total energy calculated by assuming the temperature of the helium at the burner inlet to be 40 deg R. The 29 percent increase was due to the ambient heating that occurs between the cold helium spheres and the O2-H2 burner inlet.

This large amount of ambient heating is an expected condition during acceptance testing.

Under ideal conditions, any heating above the reference should be reflected by a corresponding percentage increase in the pressurization rate above the theoretical. The actual and theoretical values do not agree because the boundary conditions vary slightly and because LH2 boil-off does not actually terminate when pressurization is initiated.

8.1.4 Ambient Helium Repressurization

Although the S-IVB-509 stage is equipped with an O2-H2 burner, the ambient helium repressurization system was retained as a redundant system. It was tested prior to the 509 J-2 firing.

The LH2 tank was satisfactorily repressurized from the five ambient helium spheres. Data and performance levels are presented in figure 8-4 and compared to S-IVB-507 and 508 data in table 8-3.

8.2 LH2 Tank Vent and Relief Operations

The LH2 tank ullage pressure was maintained at an acceptable level throughout the acceptance firing.

8.2.1 LH2 Tank Vent and Relief Valve Performance

The LH2 tank vent and relief valve and the latching valve performed satisfactorily. The LH2 tank ullage pressure profile indicates that one or both of the valves relieved from shortly after simulated liftoff to EMR cutback. Both valves relieved shortly after LH2 tank step pressurization, and valve talkbacks indicated that the valves remained partially open until after engine cutoff command.

8.2.2 Vent Operations During Simulated Coast

The continuous vent system (CVS) was operated for approximately 24 minutes prior to O2-H2 burner repressurization. Both the CVS nozzles and the nonpropulsive vent (NPV) orifices were removed, and a manifold system conducted the vented GH2 to the facility burn pond. At the LH2 tank ullage pressures maintained during the period, the flow of GH2 through the manifold (to atmospheric back pressure) was unchoked; however, choked flow at the vent exits will occur during actual orbital coast conditions. Due to the common manifold system, venting through either the CVS or NPV is reflected in the pressure data from both systems (figure 8-5).

Continuous venting was initiated by opening the relief override valve and allowing the continuous vent regulator (CVR) to open. After CVS initiation the ullage pressure decayed from 31.7 to 27.5 psia in 50 seconds, yielding a pressure decay rate of 5.3 psi/min. This is consistent with the decay rates of 4.9 and 5.1 psi/min noted on 507 and 508 stages, respectively. At 50 seconds after CVS initiation, the CVR was closed. The CVS bypass orifice was opened at CVS initiation plus 57 seconds, and the CVR was opened at CVS initiation plus 113 seconds. A nominal CVS regulation level of 20.7 psia was established.

8.3 LH2 Pump Chilldown

The LH2 pump chilldown system performed adequately. At engine start command the net positive suction pressure (NPSP) at the LH2 pump inlet was above the 4.5 psi required. The chilldown system data are presented in figures 8-6 and 8-7; the S-IVB-509 acceptance test data are compared in table 8-4 with data from two previous acceptance firings.

The chilldown system operation was initiated at SLO -299.2 seconds. System performance levels compared well with those of previous S-IVB/V acceptance firings. During unpressurized chilldown, the liquid in the system was subcooled to a point between the engine pump inlet and the chilldown system return line; the system became entirely subcooled during prepressurization. The chilldown shutoff valve was left open until shortly before engine cutoff command (ECC -45 seconds).

For the calculation of heat input to section 1 (tank to pump inlet) of the LH2 chilldown system, the reference temperature is the chilldown pump discharge temperature (C0157). Since this measurement was not installed on S-IVB-504N and subsequent stages, the LH2 bulk temperature (C0052) plus a 0.3 degree R bias was substituted. The bias was established from previous acceptance firing data.

8.4 Engine LH2 Supply

The LH2 supply system (figure 3-1) delivered the necessary quantity of LH2 to the engine pump inlet during engine firing and maintained the pressure and temperature conditions within a range that provided an LH2 pump NPSP above the minimum requirements. The data and the calculated performance are presented in figure 8-8. Table 8-5 compares the S-IVB-509 stage recorded data and calculated performance data with that from previous Saturn V acceptance firings.

During engine operation, the LH2 pump inlet temperature and pressure were very near the predicted values. The LH2 pump inlet temperature and pressure at selected times during engine operation were plotted in the engine LH2 pump operating region (figure 8-9) and showed that the engine inlet conditions were met satisfactorily throughout engine operation.

Figure 8-10 is a plot of the pump inlet temperature as a function of the propellant mass remaining in the LH2 tank and includes S-IVB-507 and 508 data comparisons. The previous test data have been biased to the LH2 pump inlet temperature observed at engine start command of the S-IVB-509 acceptance firing to correct for instrumentation error, different heating during pressurization, and other test-to-test variations.

Post-test inspection disclosed that the lower fuel duct vacuum annulus contained approximately 97 percent hydrogen and 3 percent helium. Further investigation after the lower duct had been removed revealed a crack in the lower bellows of the lower duct. This failure is similar to that which was observed during the 508 acceptance test and during the MSFC battleship testing. It is presently felt that the cracks were induced by fatigue resulting from bellows response to the LH2 flowrate at 4.5 EMR. Investigation is continuing in an effort to verify this.

TABLE 8-1

LH2 TANK PREPRESSURIZATION DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
Prepressurization duration (sec)	51.6	42.4	31.8
Helium mass added (lbm)	22.2	26.6	25.7
Ullage pressure			
At prepressurization initiation (psia)	15.2	15.2	15.2
At prepressurization termination (psia)	30.9	31.0	30.3
At simulated liftoff (psia)	31.3	31.5	31.5
At engine start command (psia)	32.1	32.3	31.7
Rate of increase after prepressurization (psi/min)	0.8	0.8	1.2
Events (sec from simulated liftoff)			
Prepressurization initiation	-94.7	-94.2	-94.1
Prepressurization termination	-43.1	-51.8	-62.3
Engine start command	511.0	511.7	511.7

TABLE 8-2

LH2 TANK PRESSURIZATION DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
Pressure switch setting			
First Burn			
Lower (psia)	29.2	28.6	28.2
Upper (psia)	30.4	30.7	30.3
Second Burn			
Lower (psia)	29.0	28.3	28.4
Upper (psia)	30.4	30.1	30.6
Ullage pressure			
At engine start command (psia)	32.3	32.3	31.7
At step pressurization (psia)	32.0	32.2	31.7
At engine cutoff command (psia)	33.0	32.9	32.1
GH2 pressurant flowrate			
Overcontrol--high EMR (lbm/sec)	--	--	--
Overcontrol--low EMR (lbm/sec)	--	--	--
Undercontrol--high EMR (lbm/sec)	0.74	0.70	0.63
Undercontrol--low EMR (lbm/sec)	0.64	0.66	0.61
Step pressurization (lbm/sec)	1.12	1.07	1.09
Total GH2 added (lbm)	342	328	281
Events (sec from simulated liftoff)			
Second burn mode initiation	861	862	712
Step pressurization initiation	921	922	921

TABLE 8-3

LH2 TANK REPRESSURIZATION DATA

Parameter	S-IVB-509		S-IVB-508		S-IVB-507	
	Ambient	Burner	Ambient	Burner	Ambient	Burner
Repressurization duration (sec)	31.6	170*	25	175*	28.9	151*
Ullage volume (cu ft)	4,600	4,670	4,663	4,697	4,519	4,559
Ullage pressure						
At repressurization initiation (psia)	20.5	19.0	22.0	19.3	21.4	20.0
At repressurization termination (psia)	30.2	30.2	30.3	30.3	30.3	30.3
Rise rate (psi/min)	18.4	3.92	19.8	3.78	18.4	4.10
Repressurization helium usage (lbm)	23.8	20.3	20.5	20.1	22.5**	18.1

* Does not include lag in repressurization initiation after burner start command

** This is not the value used in the S-IVB-507 acceptance test report; it represents an improved computation method effective with S-IVB-508.

TABLE 8-4

LH2 RECIRCULATION CHILLDOWN DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
NPSP			
At engine start command (psi)	13.5	8.9	13.3
Minimum required at start (psi)	4.5	4.5	4.5
Maximum during childown (psi)	21.2	18.9	21.0
Average flow coefficient (sec^2/in^2ft^3)	18.3	17.6	18.1
Fuel quality in sections* 2 and 3 (lb gas/lb mixture)			
Maximum--unpressurized chilldown	0.010	0.028	0.014
At prepressurization initiation	0.01	0.024	0.011
Fuel pump inlet conditions			
Static pressure at start (psia)	33.1	33.0	33.5
Temperature at start (deg R)	38.3	39.4	38.5
Amount of subcooling at start (deg R)	3.7	2.1	3.6
Heat absorption rate			
Unpressurized chilldown			
Section* 1 (Btu/hr)	7,500	20,500	10,000
Sections* 2 and 3 (Btu/hr)	18,000	18,500	18,000
Total (Btu/hr)	25,800	39,000	28,000
Pressurized chilldown			
Section* 1 (Btu/hr)	7,500	17,500	9,000
Section* 2 (Btu/hr)	13,500	12,500	12,000
Section* 3 (Btu/hr)	13,000	15,000	18,000
Total (Btu/hr)	34,000	45,000	39,000
Chilldown flowrate			
Unpressurized (gpm)	120	107	120
Pressurized (gpm)	138	138	140

*Section 1 is tank to pump inlet; section 2 is pump inlet to bleed valve; section 3 is bleed valve to tank.

Table 8-4 (Continued)

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
Chilldown pump pressure differential			
Unpressurized (psi)	8.5	8.9	8.7
Pressurized (psi)	7.6	7.2	7.8
Events (sec from simulated liftoff)			
Chilldown initiated	-299.2	-298.7	-298.6
Prevalve closed	-283.6	-283.3	-283.2
Prepressurization	-94.7	-94.2	-94.1
Prevalve opened	509.2	510.1	510.2
Chilldown pump off	510.4	511.1	511.2
Engine start command	511.0	511.7	511.7
Chilldown shutoff valve closed	921.7	922.2	922.2

TABLE 8-5

LH2 PUMP INLET CONDITION DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
Pump inlet conditions			
Static pressure at engine start command (psia)	33.1	33.0	33.5
Static pressure at engine cutoff command (psia)	31.6	30.2	31.7
Temperature at engine start command (deg R)	38.3	39.4	38.5
Temperature at engine cutoff command (deg R)	39.0	39.9	39.0
NPSP requirements at pump interface			
Minimum at engine start command (psi)	4.5	4.5	4.5
At high EMR (psi)	5.3	5.3	5.3
After EMR cutback (psi)	4.9	4.9	4.9
NPSP available at pump interface			
At engine start command (psi)	11.5	8.9	13.3
Maximum (psi)	16.2	16.3	15.9
Minimum (psi)	10.7	10.2	11.0
At engine cutoff command (psi)	11.5	11.2	11.0
LH2 suction duct			
At high EMR			
Pressure drop (psi)	0.8	0.6	0.3
Flowrate (lbm/sec)	84	82	85
After EMR cutback			
Pressure drop (psi)	0.8	0.5	0.5
Flowrate (lbm/sec)	81	79	84

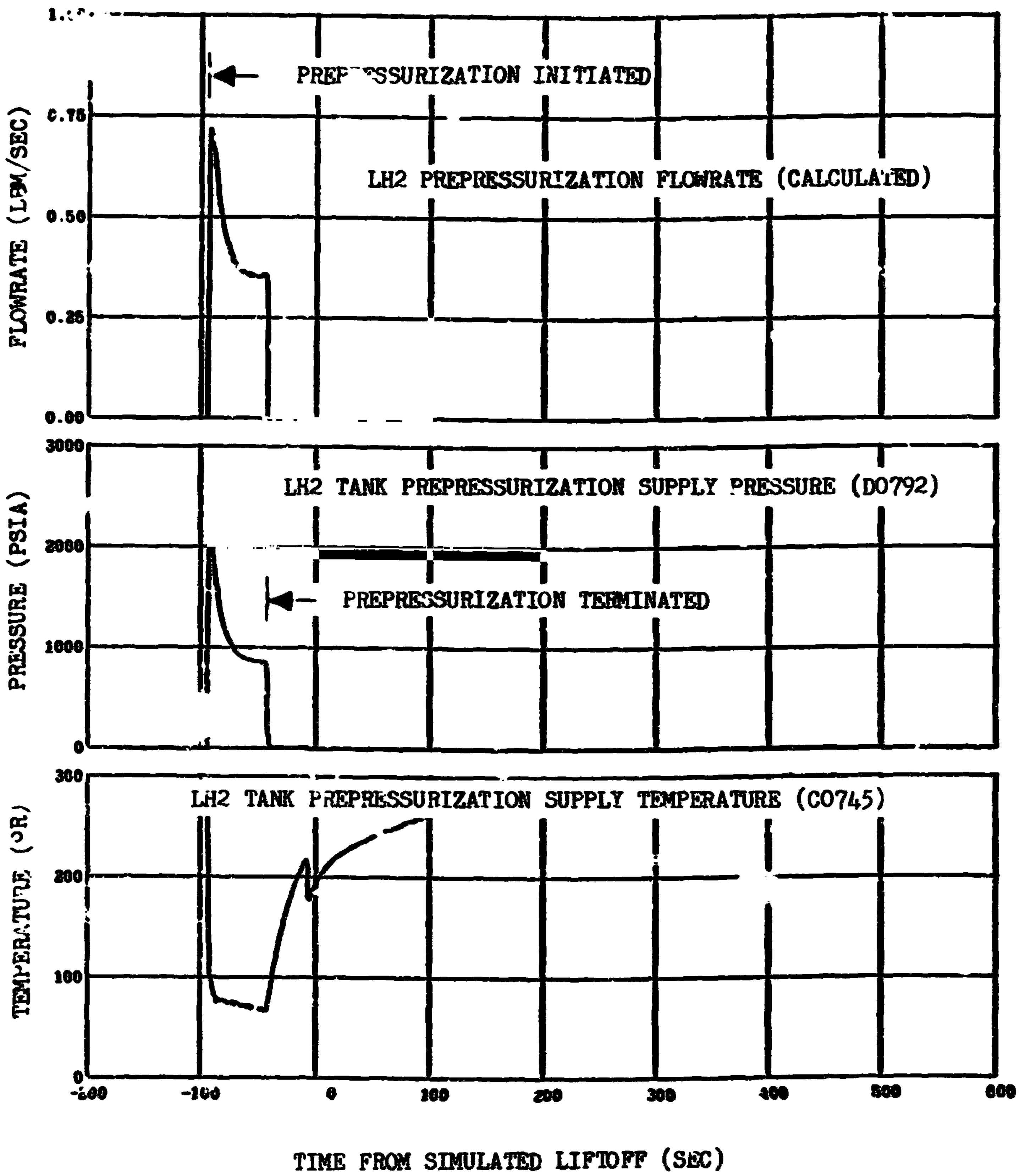


Figure 8-1. LH2 Tank Prepressurization System Performance (Sheet 1 of 2)

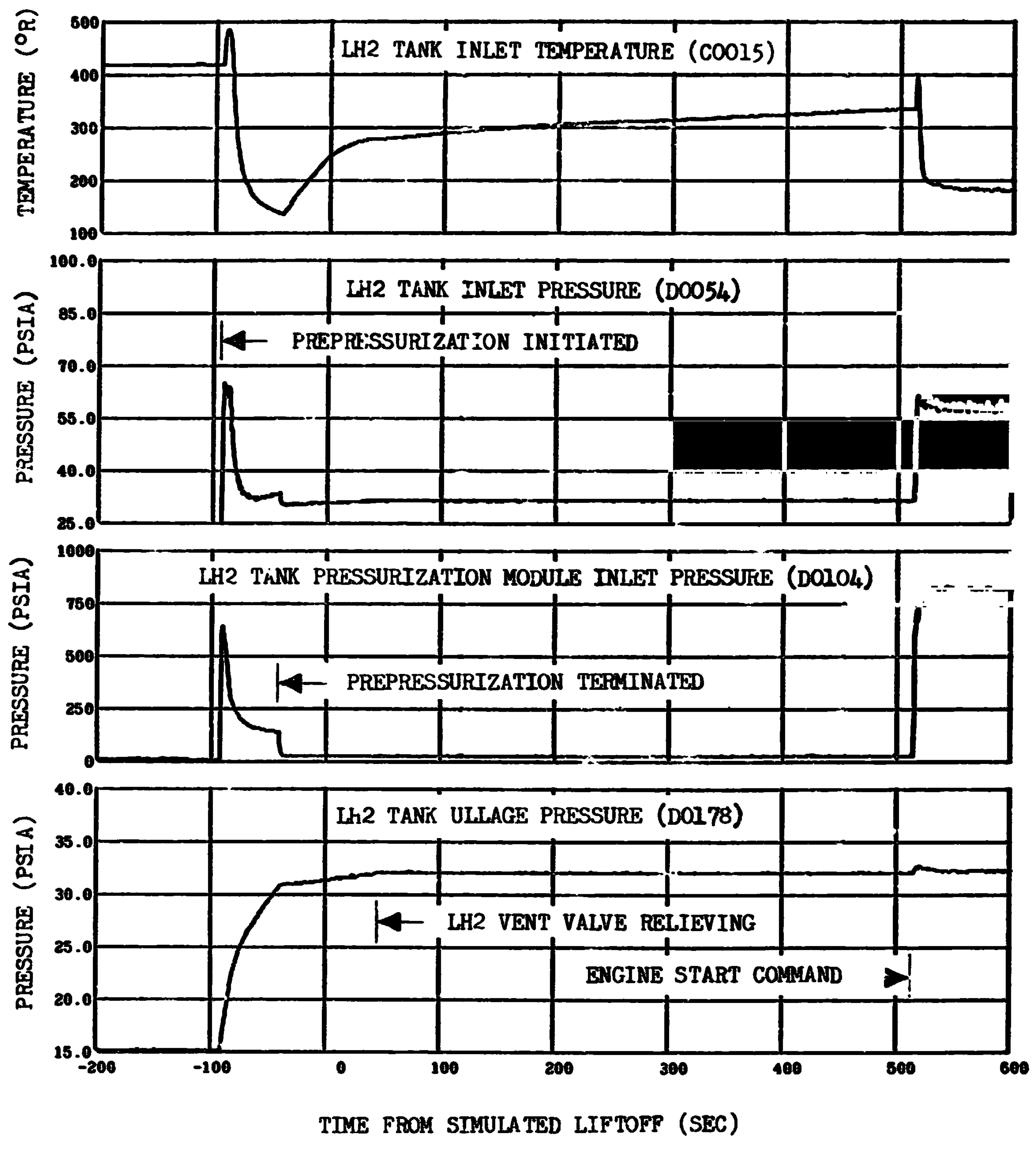


Figure 8-1. LH2 Tank Prepressurization System Performance (Sheet 2 of 2)

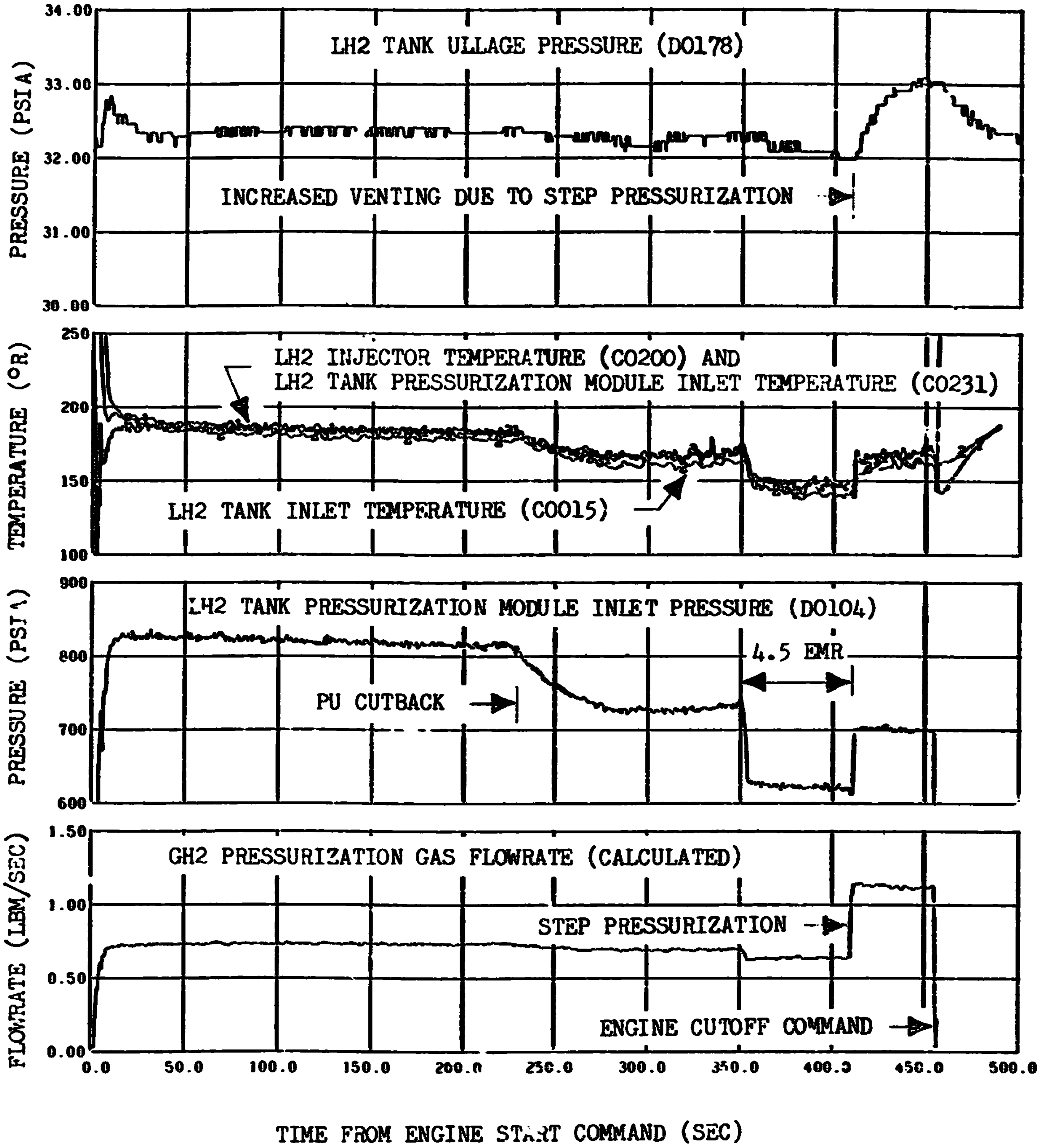


Figure 8-2. LH2 Tank Pressurization System Performance

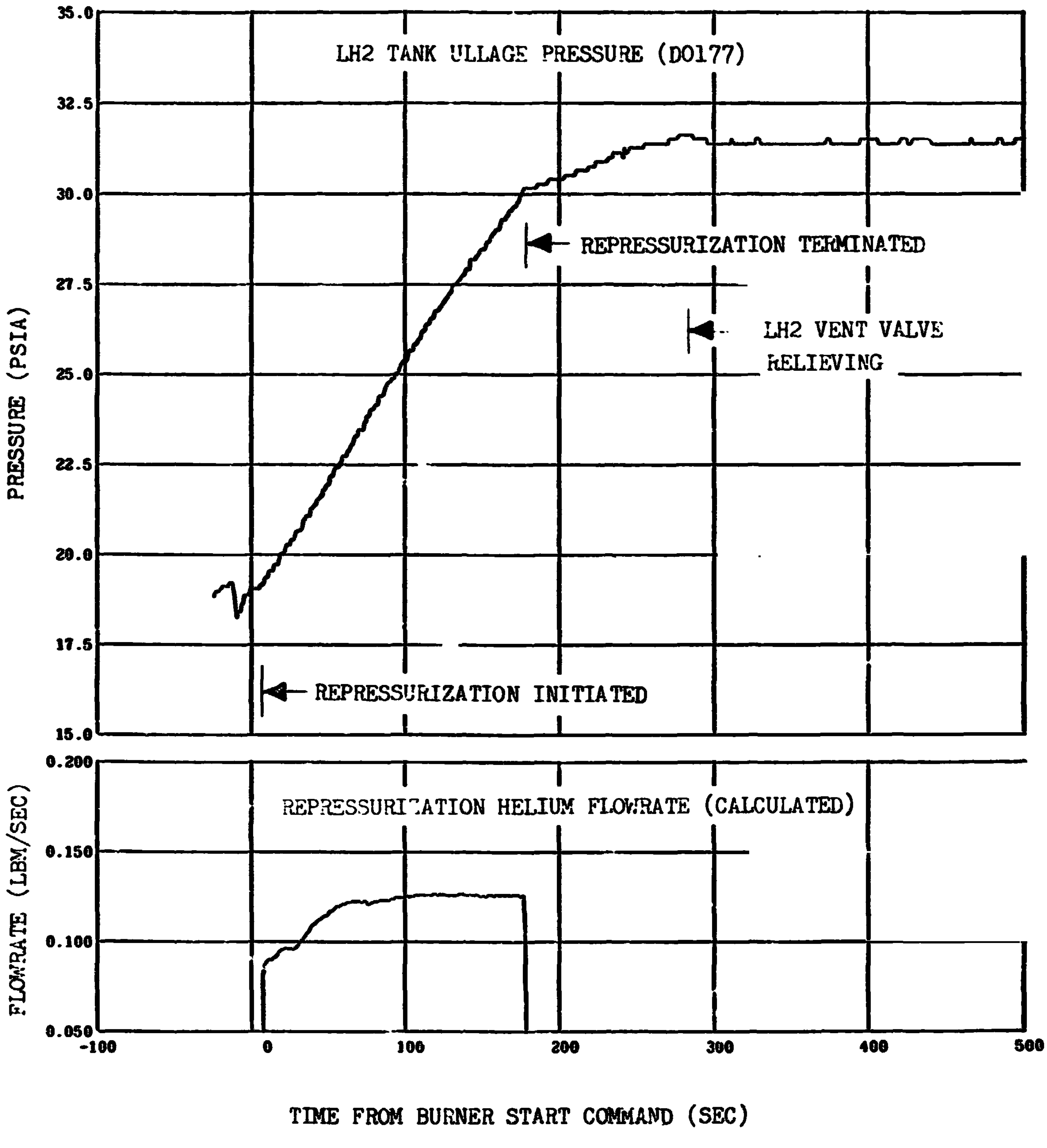


Figure 8-3. LH2 Tank O2-H2 Burner Repressurization

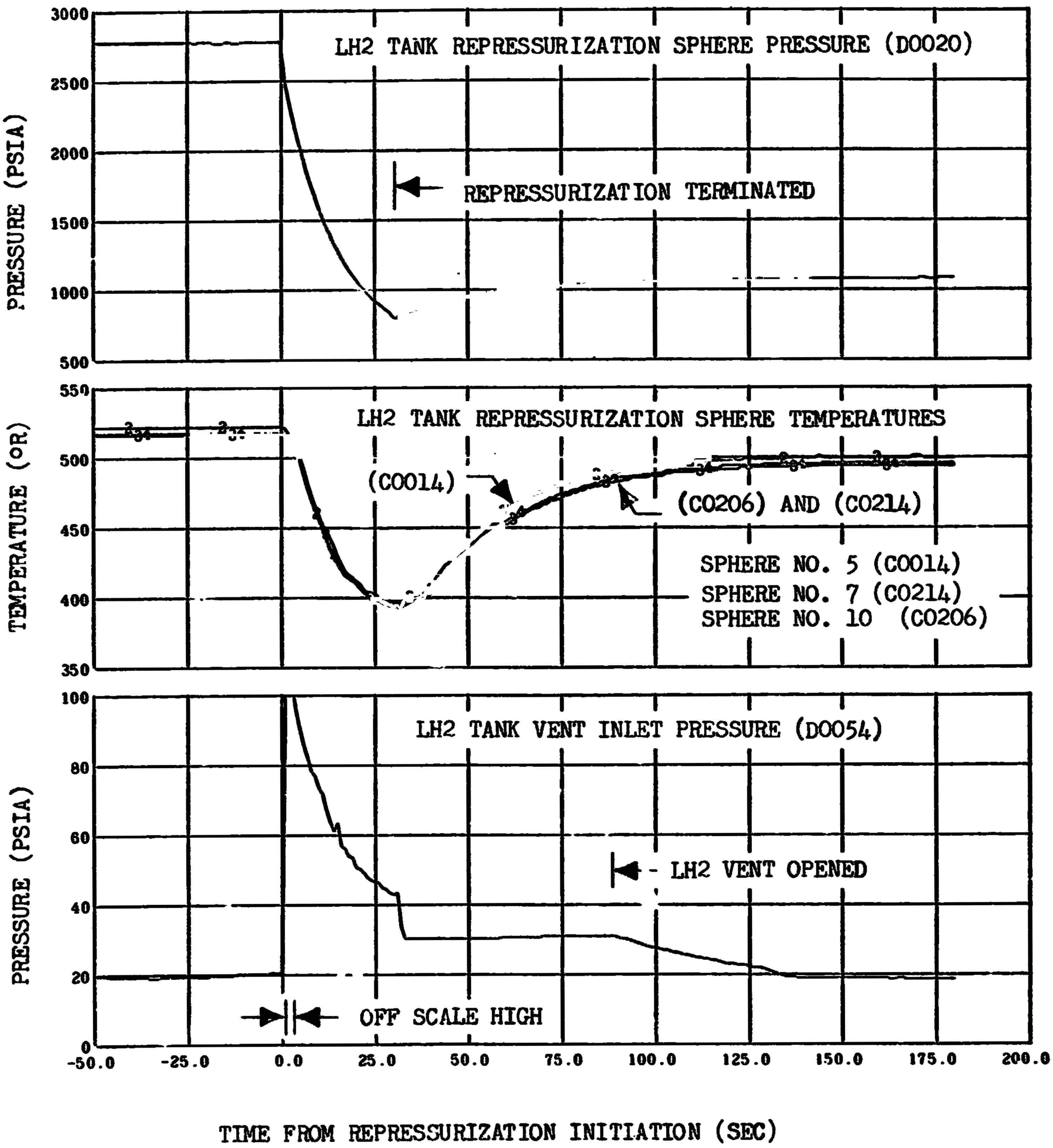


Figure 8-4. LH2 Tank Ambient Helium Repressurization System Performance (Sheet 1 of 2)

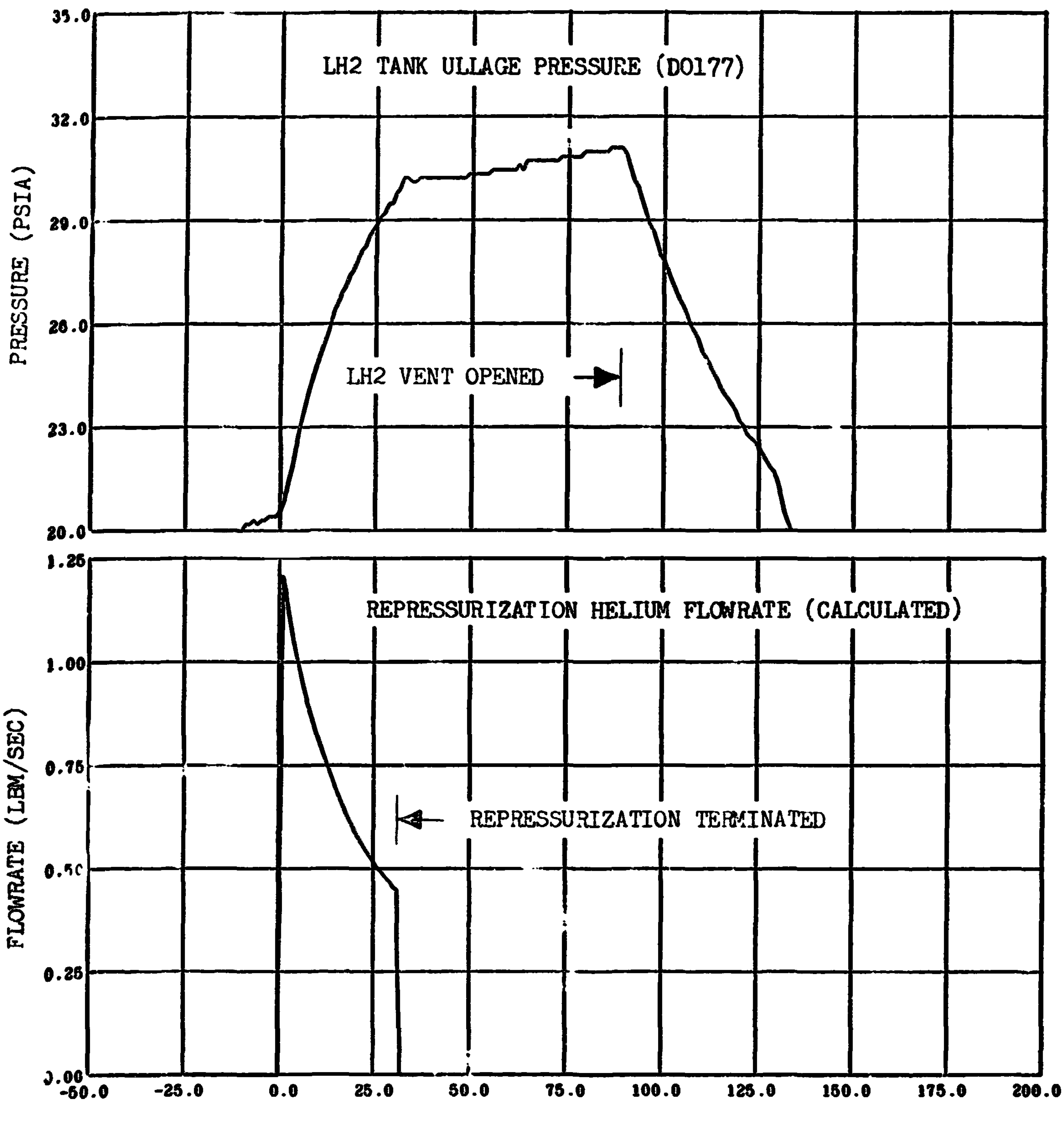


Figure 8-4. LH2 Tank Ambient Helium Repressurization System Performance (Sheet 2 of 2)

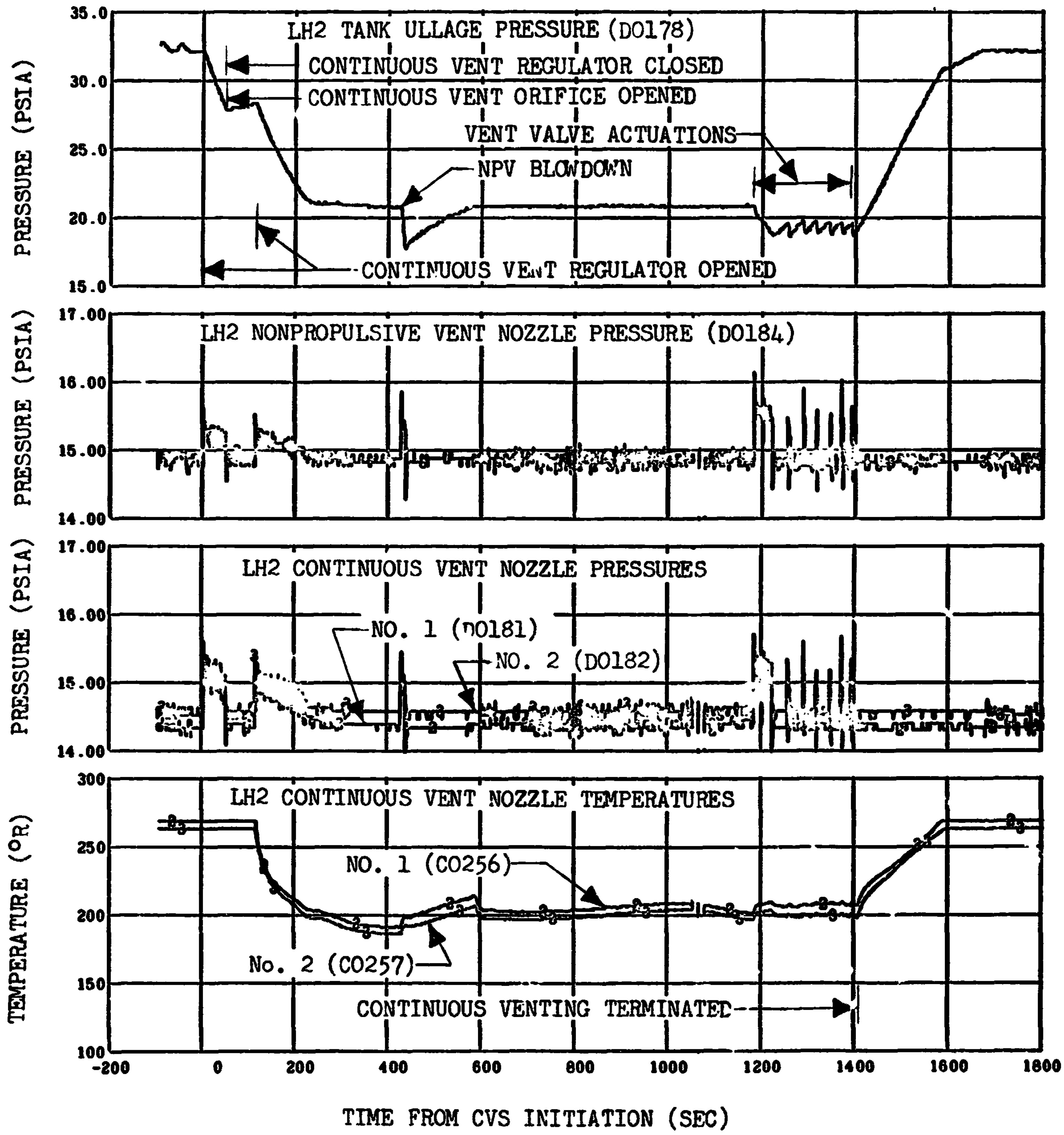


Figure 8-5. LH2 Tank Venting System Operation

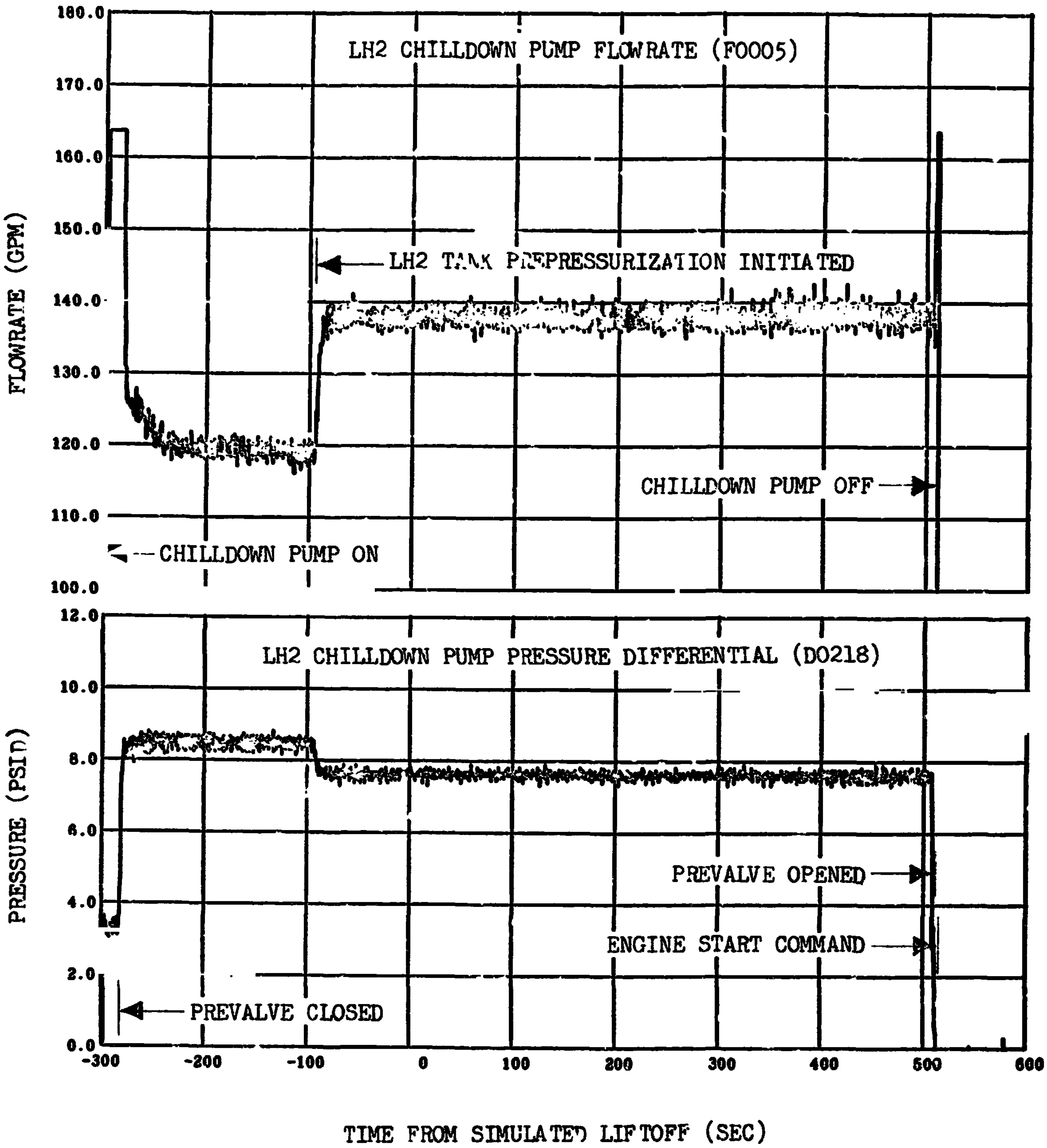


Figure 8-6. LH2 Pump Chilldown (Sheet 1 of 3)

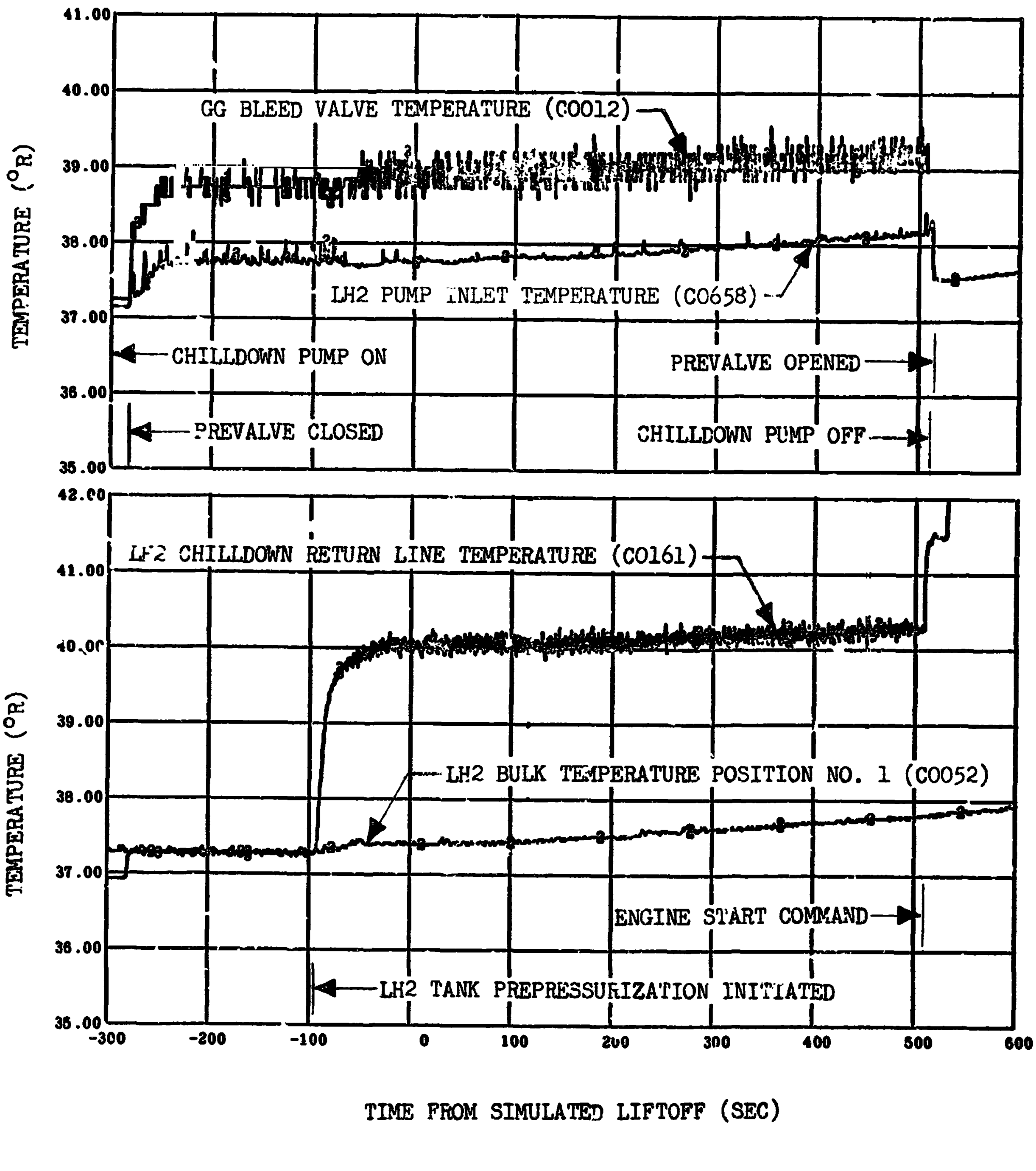


Figure 8-6. LH2 Pump Chilldown (Sheet 2 of 3)

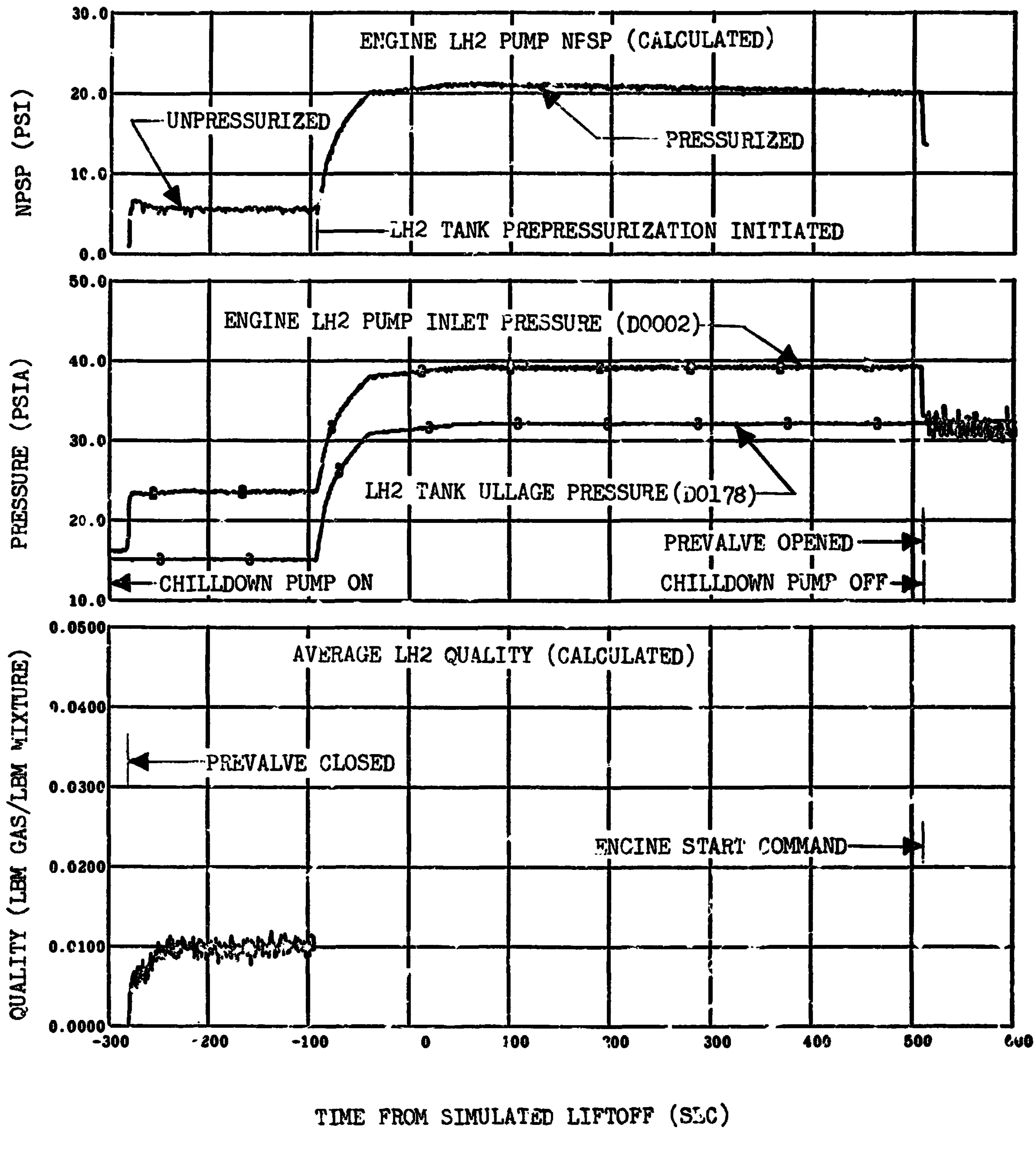


Figure 8-6. LH2 Pump Chilldown (Sheet 3 of 3)

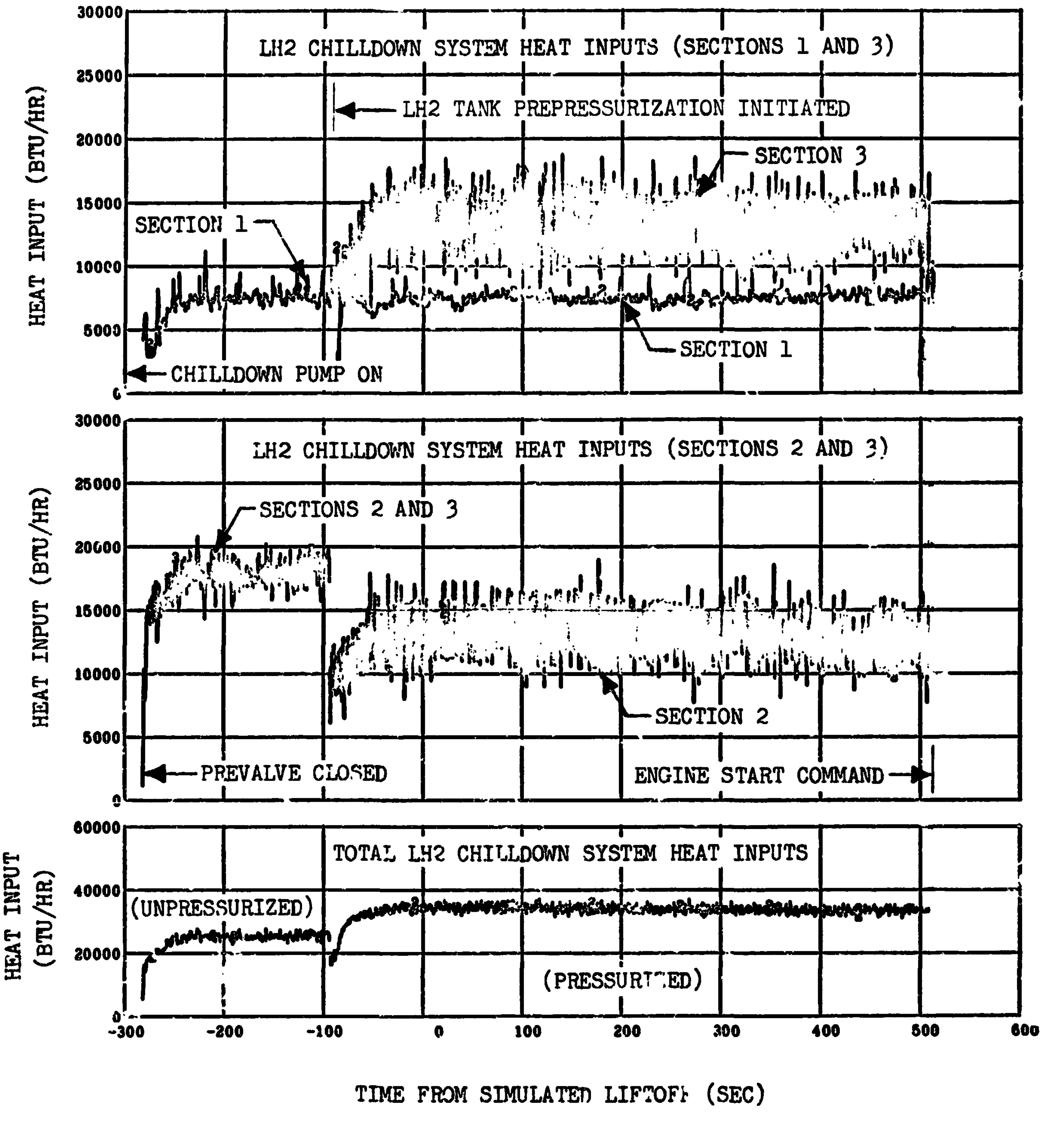


Figure 8-7. LH2 Pump Chilldown Characteristics

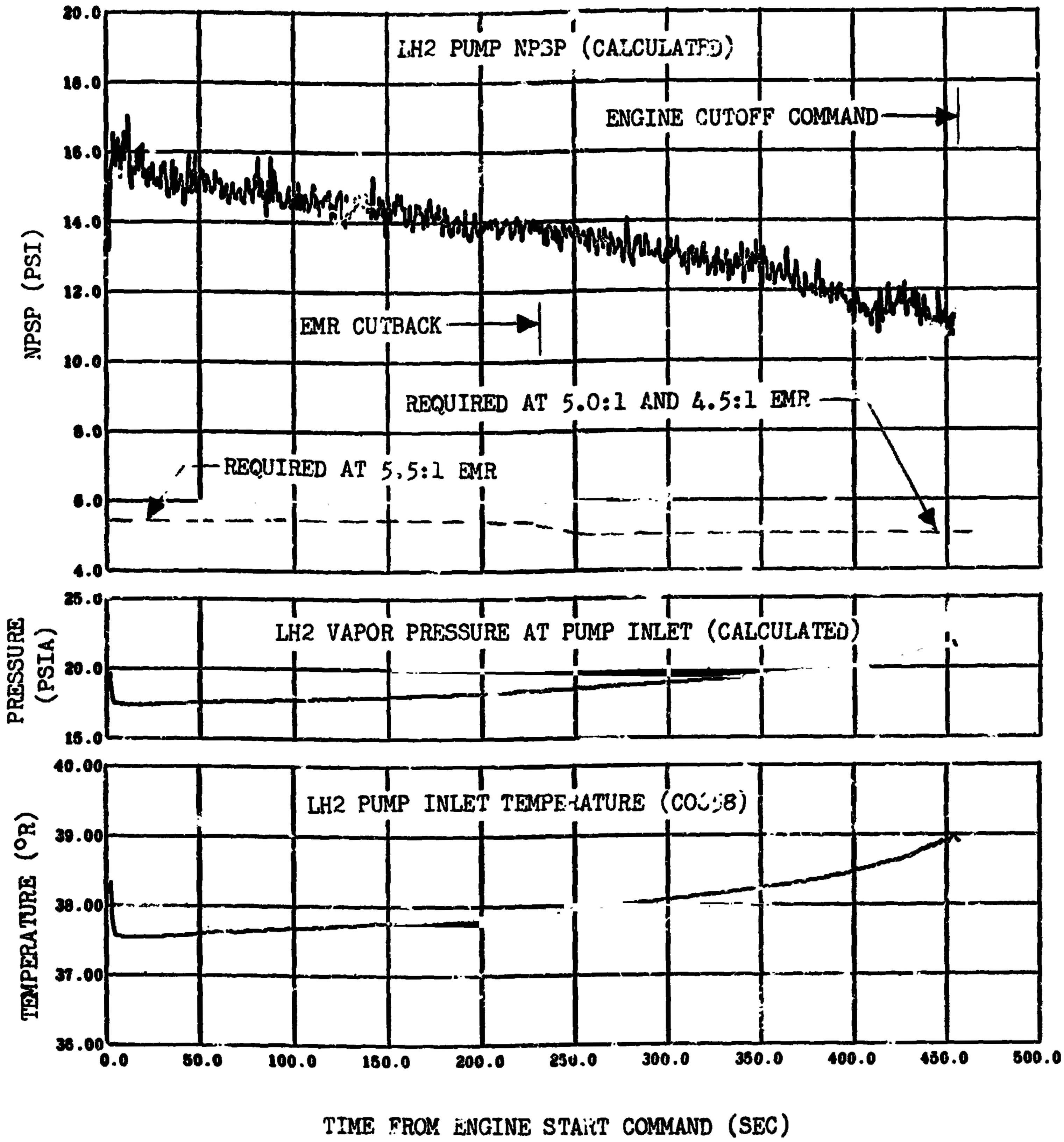


Figure 8-8. LH2 Pump Inlet Conditions (Sheet 1 of 2)

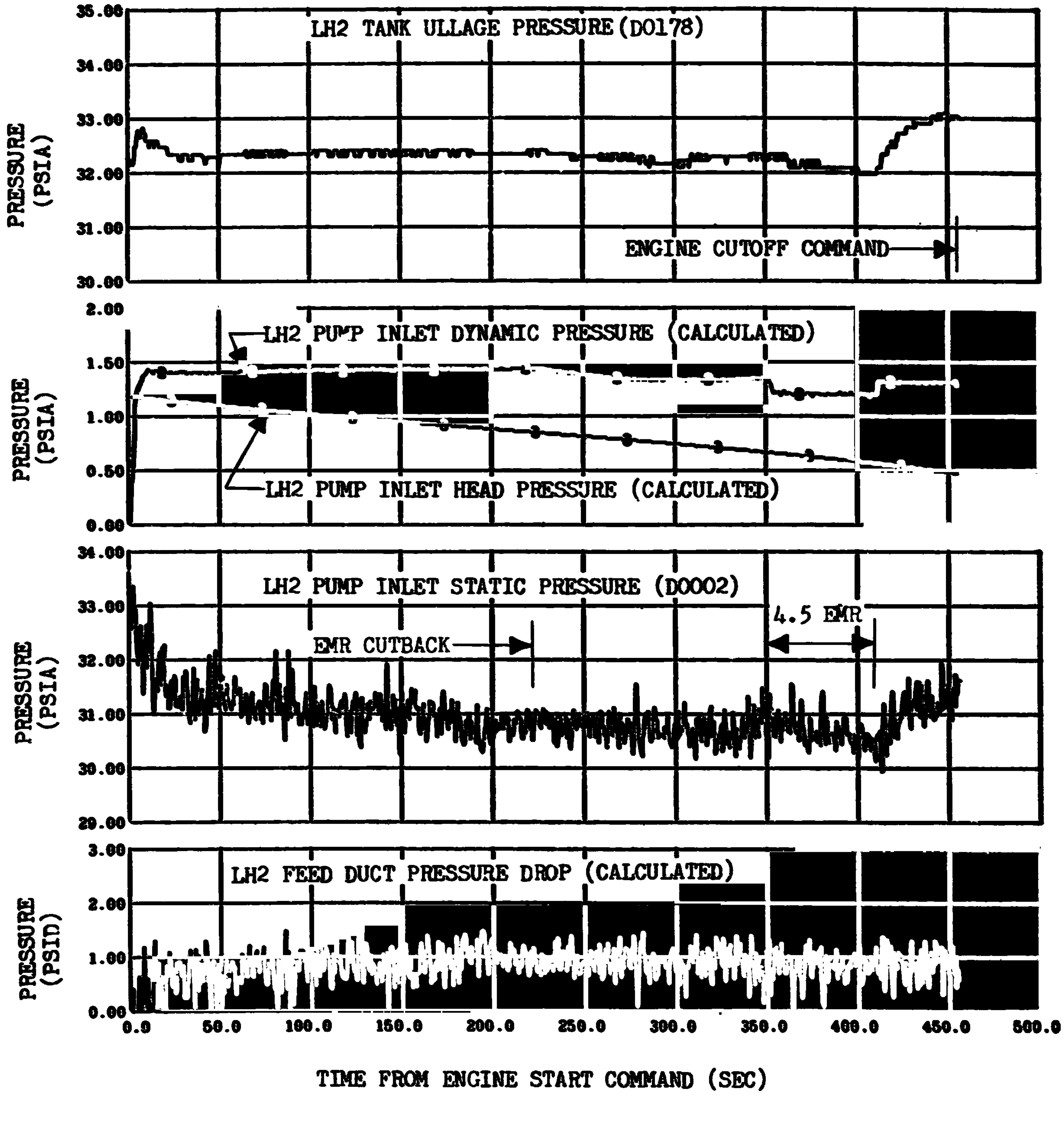


Figure 8-8. LH2 Pump Inlet Conditions (Sheet 2 of 2)

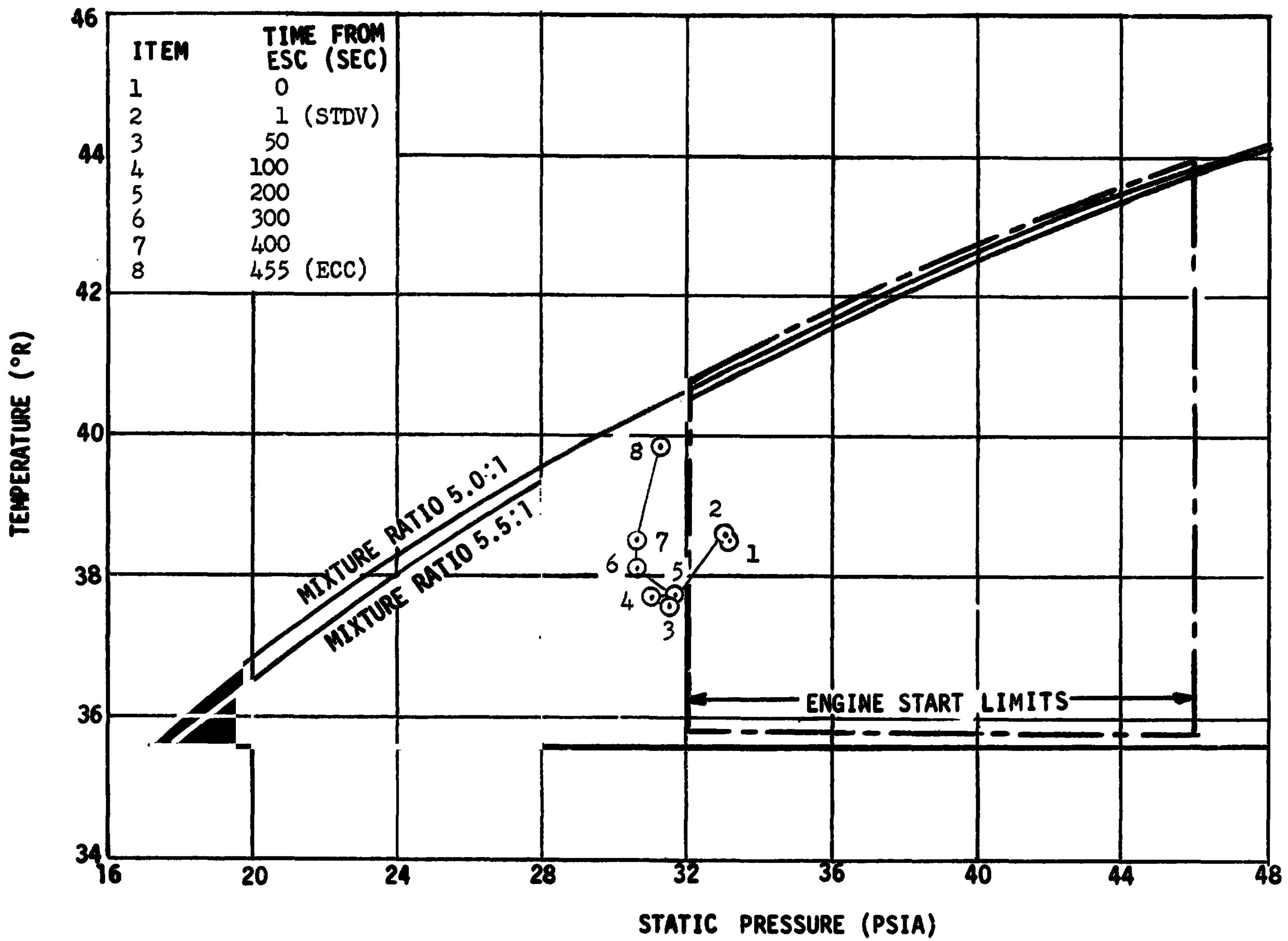


Figure 8-9. LH2 Pump Inlet Conditions During Firing

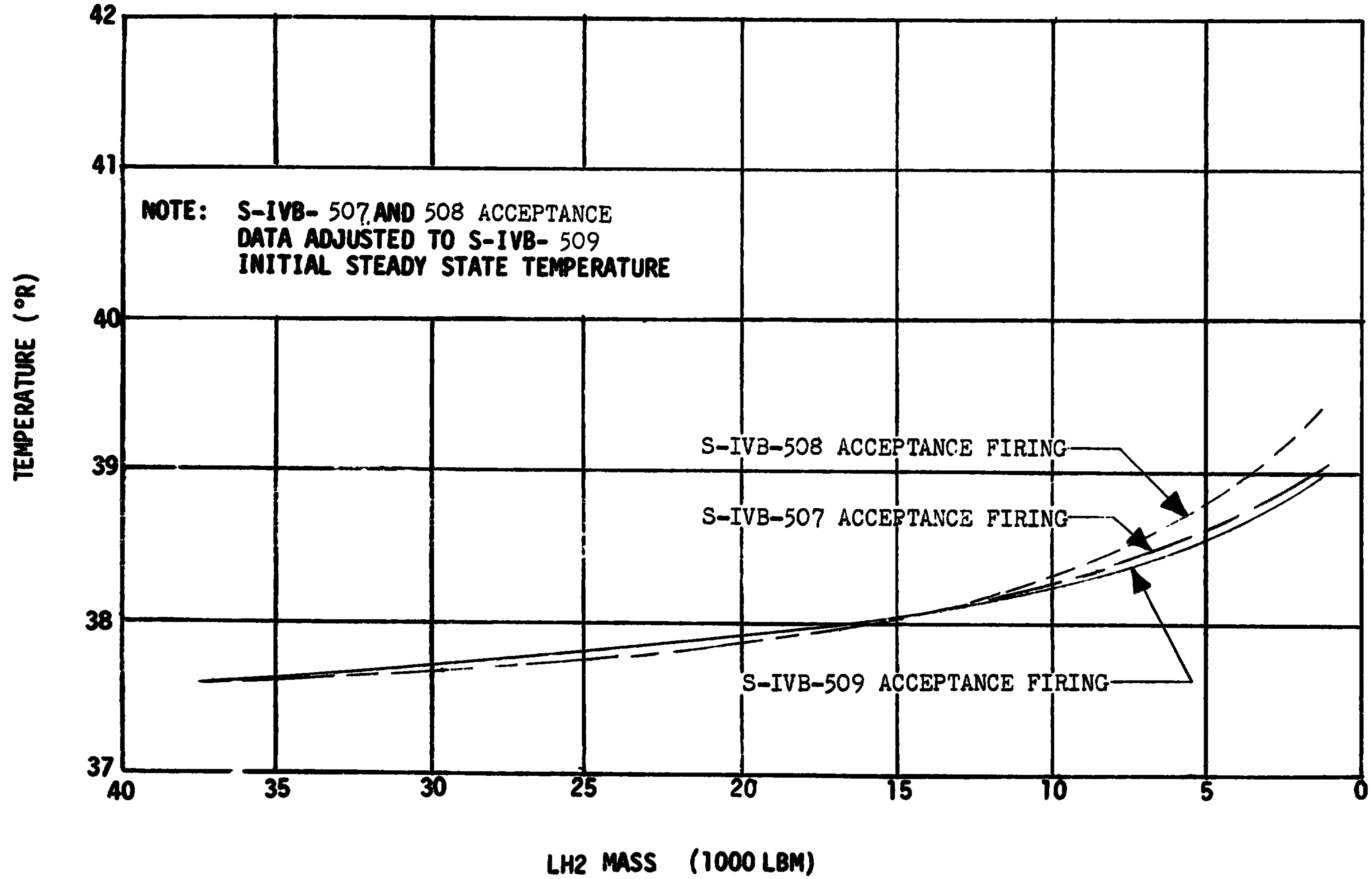


Figure 8-10. Effect of LH2 Mass Level on LH2 Pump Inlet Temperature

9. PNEUMATIC CONTROL AND PURGE SYSTEM

The pneumatic control and purge system (figure 3-1) performed adequately during the acceptance firing. All components functioned properly. The test results are summarized and compared with previous acceptance firing data in table 9-1.

9.1 Ambient Helium Supply

In order to simulate actual flight conditions the stage was isolated from the ground support equipment (GSE). The helium supply valve was closed 349.1 seconds prior to simulated coast and remained closed during the continuous venting period and both the burner and ambient helium repressurization operations. The valve was also closed at SLO -7.8 seconds and remained closed through J-2 engine operation.

9.2 Pneumatic Control

All engine and stage pneumatic control valves responded properly throughout the terminal countdown, simulated coast, O2-H2 burner operation, ambient repressurization, and J-2 engine operation.

During a period of simulated coast the pressure decay of the control helium sphere was higher than normal because of the high bleed rate that accompanies actuation of the latch in the LH2 latching vent and relief valve. The latch in the LH2 latching vent and relief valve remained actuated from *BSC -358 seconds to BSC +826 seconds.

A revised calibration specification resulted in a nominal regulator lock-up level of 510 psig (525 psia on the ground) as opposed to the previous lock-up level of 535 psig. Operating data during the test (figure 9-1) indicate the change was effective in holding regulator discharge pressure to a reasonable level.

The normal system pressure drops that result from regulator operation during J-2 engine and O2-H2 burner operation are shown in figures 9-1 and 9-2, respectively.

*Burner Start Command

9.3 Ambient Helium Purges

During the acceptance firing all stage purge functions that utilize stage pneumatics were satisfactorily accomplished. The pneumatic system was isolated from the GSE during the periods of simulated coast and engine firing, discontinuing those purges that were facility supplied. Table 3-2 lists the flowrates of the various purge orifices.

TABLE 9-1

PNEUMATIC CONTROL AND PURGE SYSTEM DATA

Parameter	S-IVB-509		S-IVB-508		S-IVB-507	
	Engine Operation	Burner Operation	Engine Operation	Burner Operation	Engine Operation	Burner Operation
Sphere volume (cu ft)	4.5	4.5	4.5	4.5	4.5	4.5
Sphere pressure						
At simulated liftoff (psia)	2,935	--	2,950	--	2,966	--
At engine start command (psia)	2,860	2,552	2,875	2,540	2,855	2,175 1,941*
At engine cutoff command (psia)	2,850	2,500	2,860	2,500	2,852	2,024 1,903*
Sphere temperature						
At simulated liftoff (deg R)	548	--	547	--	540	--
At engine start command (deg R)	541	533 --	540	532	534	526 523*
At engine cutoff command (deg R)	538	533 --	540	531	533	523 522*
Helium mass usage rate						
Pre-burn engine pump purge (lbm/min)	0.053	--	0.075	--	0.070	--
Post-burn engine pump purge (lbm/min)	0.105	--	0.120	--	0.146	--
Simulated coast with no engine pump purge (lbm/min)	0.012	--	0.027	--	0.010	--
Burn duration (sec)	455.3	460	460	460	436	455 130*

*Value obtained from second burner operation.

Table 9-1 (Continued)

Parameter	S-IVB-509		S-IVB-508		S-IVB-507	
	Engine Operation	Burner Operation	Engine Operation	Burner Operation	Engine Operation	Burner Operation
Helium mass						
At simulated liftoff (lbm)	8.05	--	8.12	--	8.39	--
At engine start command (lbm)	7.96	7.3	8.01	7.27	8.19	6.46 5.85*
At engine cutoff command (lbm)	7.96	7.14	8.01	7.16	8.19	6.07 5.74*
Usage during engine or burner operation (lbm)	0.0	0.16	0.0	0.11	0.0	0.39 0.11*
Usage during 10-min post-burn engine pump purge** (lbm)	1.25	--	1.20	--	1.46	--
Maintained regulator outlet pressure band						
Low (psia)	480	495	550	548	534	540 540*
High (psia)	495	500	565	552	565	543 542*
System minimum during start and cutoff transient (psia)	403	--	440	--	426	--
Average LOX childown motor container purge pressure (psia)	50	50	45	46	61	60

* Value obtained from second burner operation.

**Estimated on basis of purge flowrate.

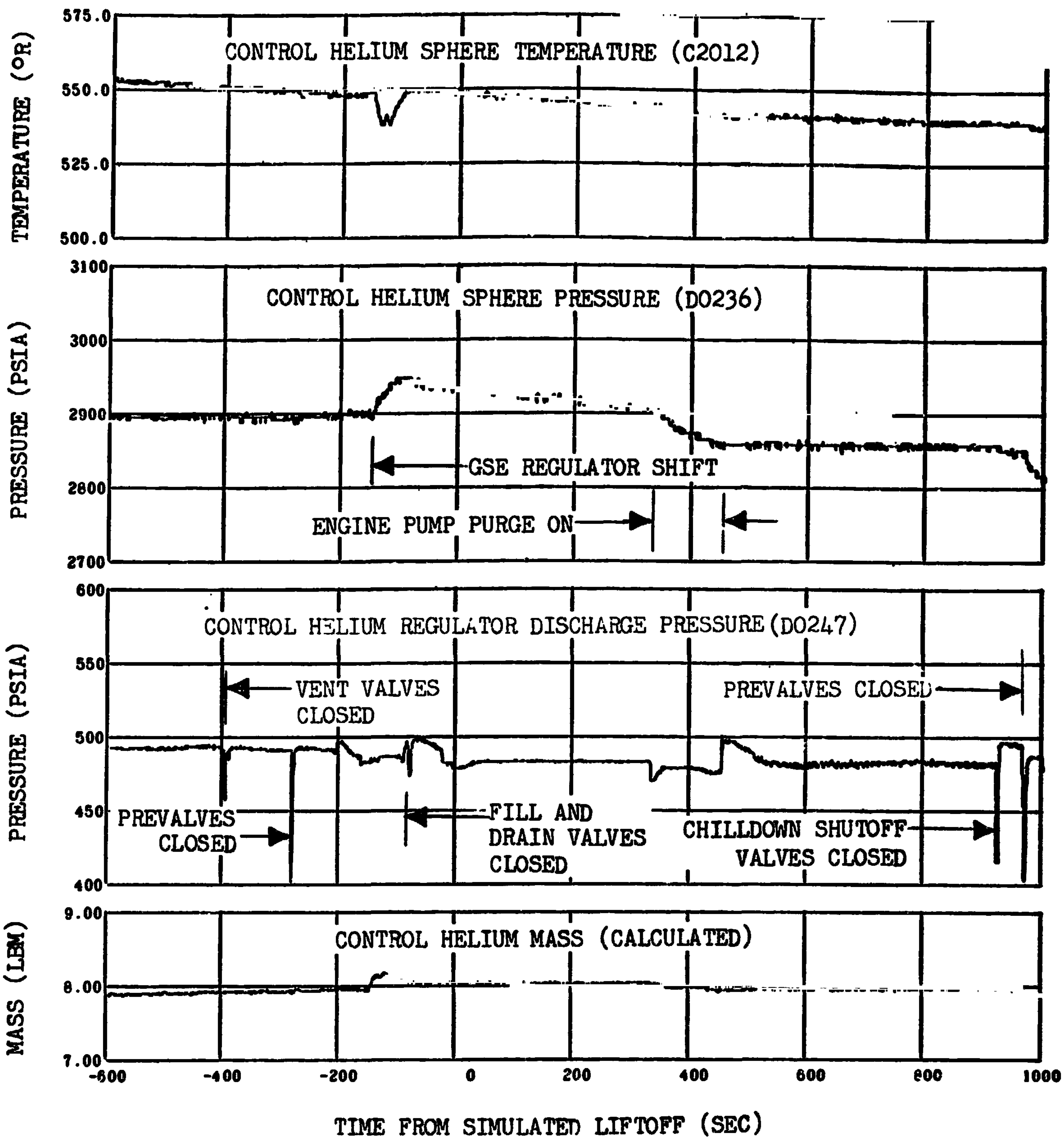


Figure 9-1. Pneumatic Control and Purge System Performance

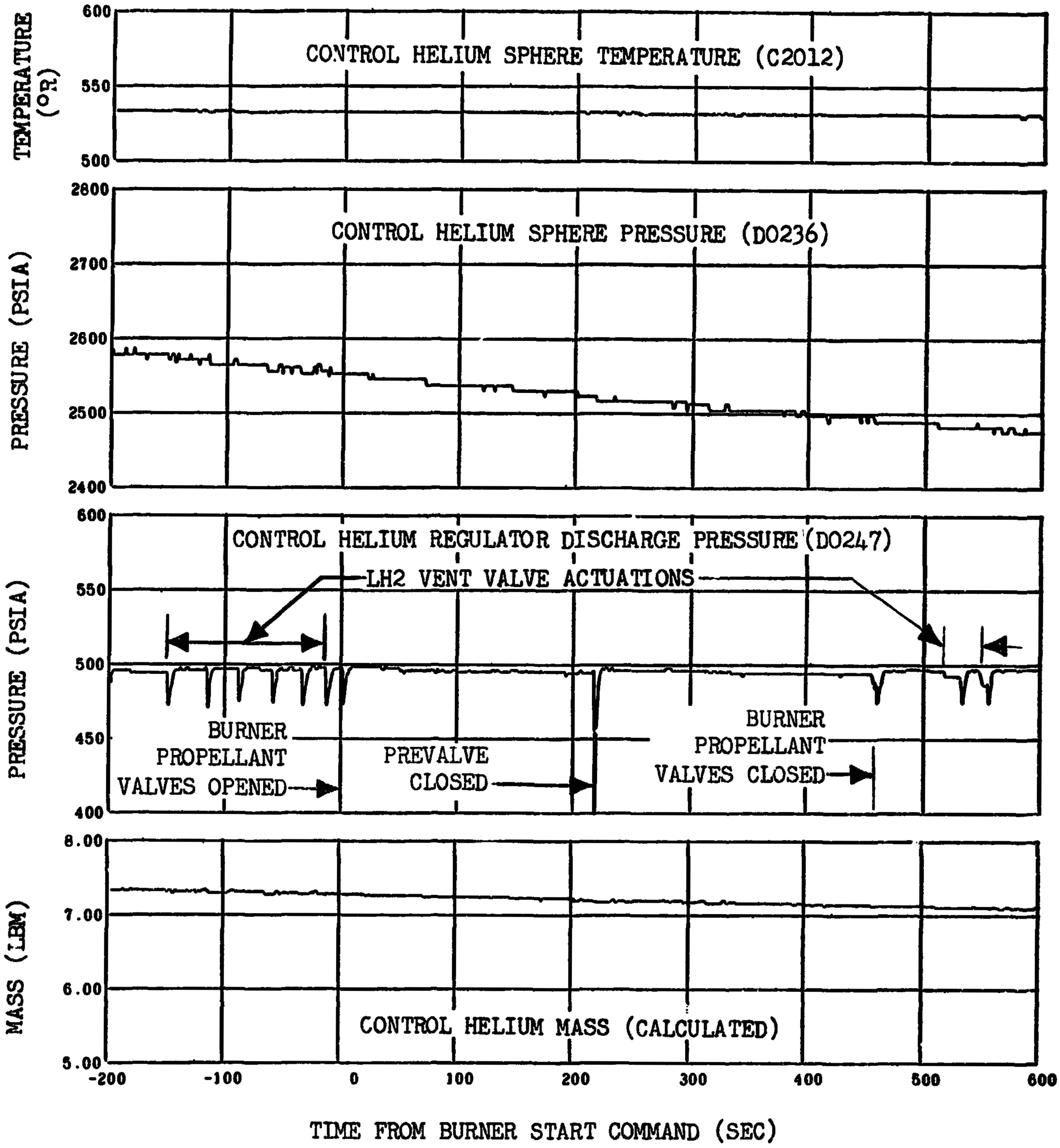


Figure 9-2. Pneumatic Control System Conditions
During O2-H2 Burner Operation

10. OXYGEN-HYDROGEN BURNER SYSTEM

The O2-H2 burner (figure 3-1) was acceptance tested prior to the S-IVB-509 stage acceptance firing. The 509 test differed from previous acceptance tests in two ways. The S-IVB-503N, 504N, and 505N burner operations were terminated by pickup of the LH2 flight control pressure switch, whereas the 506N, 507, 508, and 509 burner operations were not. In addition, the burner was operated twice during the 506N and 507 acceptance tests--the first time to repressurize the LH2 and LOX tanks, and the second to show the burner restart capability for ullaging purposes. On S-IVB-508 and 509, however, the burner was operated only once.

10.1 Burner Performance

The burner performed satisfactorily during the 460 seconds of operation. The LH2 tank was repressurized 177.3 seconds after burner start, and the LOX tank repressurization was terminated approximately 0.2 seconds later. Performance data are presented in figures 10-1 through 10-4.

10.2 LH2 Tank Repressurization

The LH2 tank pressurant started flowing 6.9 seconds after burner start command. The LH2 tank ullage was then pressurized from 19.0 to 30.2 psia in 170.4 seconds, for an average rate of 3.92 psi/min.

The 3.92 psi/min repressurization rate was 0.67 psi/min higher than the theoretical rate based on an adiabatic repressurization process, utilizing 40 deg R helium. The higher than theoretical pressurization rate was the result of the relatively warm temperatures of the cold helium [illegible]eres. As on the 508 burner, the ambient heating on the S-IVB-509 bu[illegible] was less than on the 507 burner due to different cold helium sphere conditions on the various tests.

The LH2 tank repressurization coil outlet temperature and pressure and the helium flowrate are shown in figure 10-2 and further discussed in paragraph 8.1.3. A comparison of O2-H2 burner performance during three acceptance firings is presented in table 10-1.

10.3 LOX Tank Repressurization

The LOX tank pressurant started flowing 7.1 seconds after burner start command. The LOX tank ullage was then repressurized from 34.2 to 37.2 psia in 170.4 seconds, for an average rate of 1.06 psi/min. To compensate for the 4.64 psia head due to the LOX load during ground testing, the ullage pressure was kept low enough to provide a burner LOX supply pressure range of 38.8 to 41.8 psia.

The total average LOX tank repressurization heat flux (the heating of the LOX tank pressurant gas from the 40 deg R reference base to the burner LOX repressurization outlet temperature) was 49,100 Btu/hr. Ambient heating (the heating of the LOX tank pressurant gas from the 40 deg R reference base to the burner inlet temperature) contributed approximately 10,300 Btu/hr to the total LOX tank repressurization heat flux. As a result of the cold helium sphere temperatures, the ambient heating and the LOX repressurization heat flux were comparable to those on previous acceptance tests. Approximately 4.4 lbm of helium were required for LOX tank repressurization.

At repressurization termination a spike occurred in the LOX repressurization coil outlet pressure, measurement D0228, due to an increase in the back pressure of the cold helium supply system. The increase occurred because the LH2 repressurization valves closed shortly before (0.2 second) the LOX repressurization valves.

The helium flowrate and the LOX tank repressurization coil outlet temperature and pressure are shown in figure 10-3 and are further discussed in paragraph 7.1.3. The 509 acceptance firing LOX tank repressurization performance is compared with 507 and 508 acceptance performance in table 10-1.

10.4 Cold Helium Supply

The cold helium spheres provided an adequate amount of helium for cryogenic repressurization. The temperature and pressure profiles before and during burner operation were as expected and are shown in figure 10-4. The system performance is compared with previous acceptance tests in table 10-1.

10.5 Pilot Bleed Flowrate

The burner helium shutoff valves utilize a pilot bleed system which diverts approximately 0.004 lbm/sec of the total cold helium flow passing through each module and dumps it downstream of the burner exit orifices. This pilot bleed flow is compared with that during the S-IVB-507 and 508 tests in table 10-1.

TABLE 10-1

O2-H2 BURNER PERFORMANCE DATA

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
Duration of burner operation			
First burn	460.0	459.6	455.5
Second burn	N/A	N/A	130.6
Lag in pressurant flow after burn initiation (sec)	6.89	7.49	6.87
Cold helium supply			
Initial pressure (psia)	1,825	1,625	1,763
Initial average temperature (deg R)	64.3	61.6	64.0
Initial mass (lbm)	242.5	223	224
Consumption during burner operation (lbm)	24.7	25.0	22.5
Burner propellant supply during repressurization period			
LH2 supply pressure range (psia)	20.0-31.0	20.2-31.2	20.9-31.1
LOX supply pressure range (psia)	38.8-41.8	39.1-42.5	38. -41.1
LH2 tank pressurization			
Ullage volume (cu ft)	4,670	4,697	4,619
Initial pressure (psia)	19.0	19.3	20.0
Final pressure (psia)	30.2	30.3	30.2
Average pressurization rate (psi/min)	3.92	3.78	4.05
Total average heat transfer rate* (Btu/hr)	240,000	244,000	243,000
Ambient heating rate* of pressurant gas (Btu/hr)	54,580	53,350	64,000
Pressurant helium through burner (lbm)	19.6	19.36	18.1
Pressurant helium through valve pilot bleed (lbm)	0.73	0.74	0.61
Total helium required (lbm)	20.3	20.1	18.71

* Measured from 40 deg R reference base

Table 10-1 (Continued)

Parameter	S-IVB-509	S-IVB-508	S-IVB-507
LOX tank pressurization			
Ullage volume (cu ft)	1,126	974	969
Initial pressure (psia)	34.2	34.5	33.7
Final pressure (psia)	37.2	37.9	36.5
Average pressurization rate (psi/min)	1.06	1.20	1.11
Total average heat input rate* from burner (Btu/hr)	49,090	47,093	48,200
Ambient heating rate* of pressurant gas (Btu/hr)	10,290	10,188	11,500
Pressurant helium through burner (lbm)	3.66	2.90	3.20
Pressurant helium through valve pilot bleed (lbm)	0.72	0.71	0.61
Total helium required (lbm)	4.38	3.61	3.81

* Measured from 40 deg R reference base

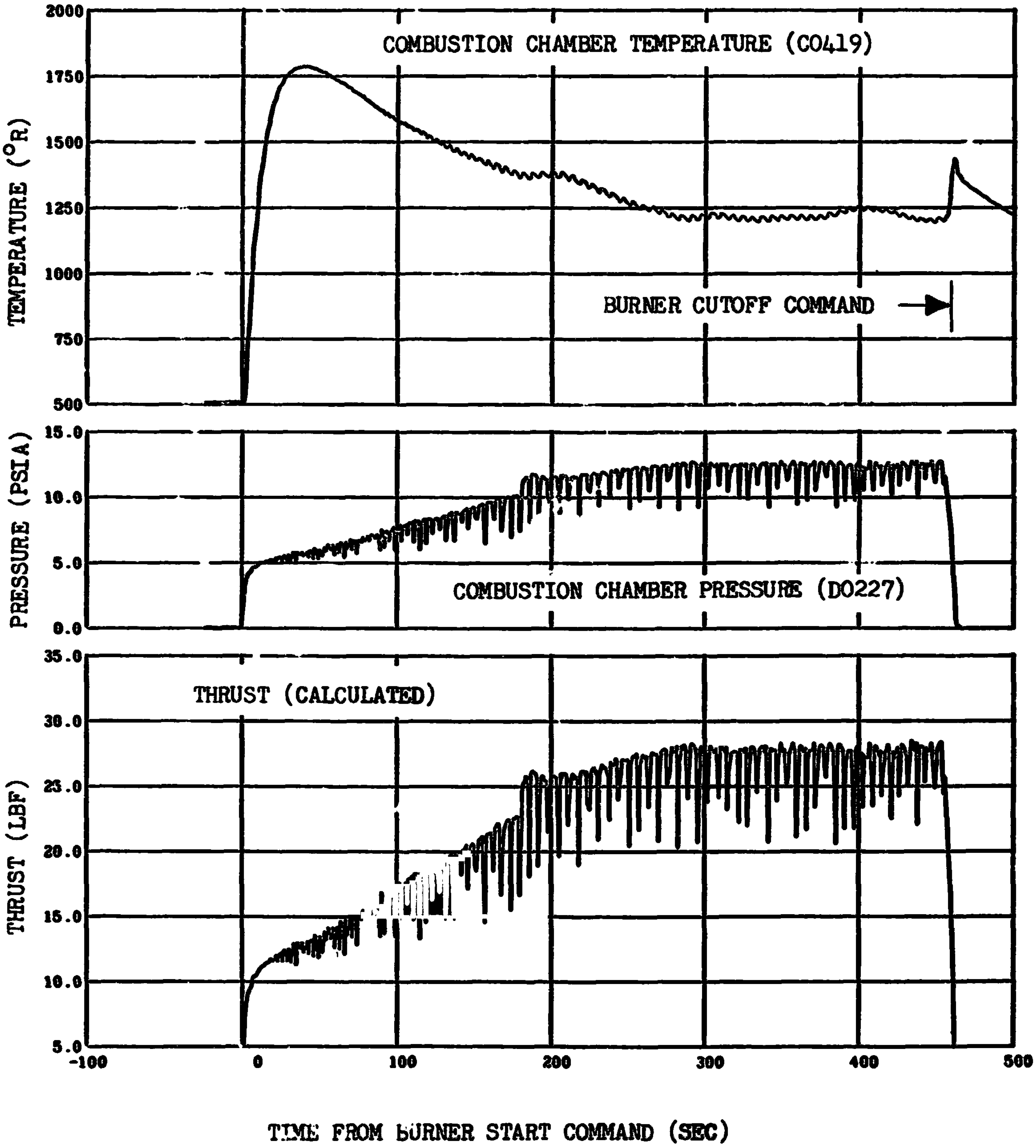


Figure 10-1. Burner Operation (Sheet 1 of 2)

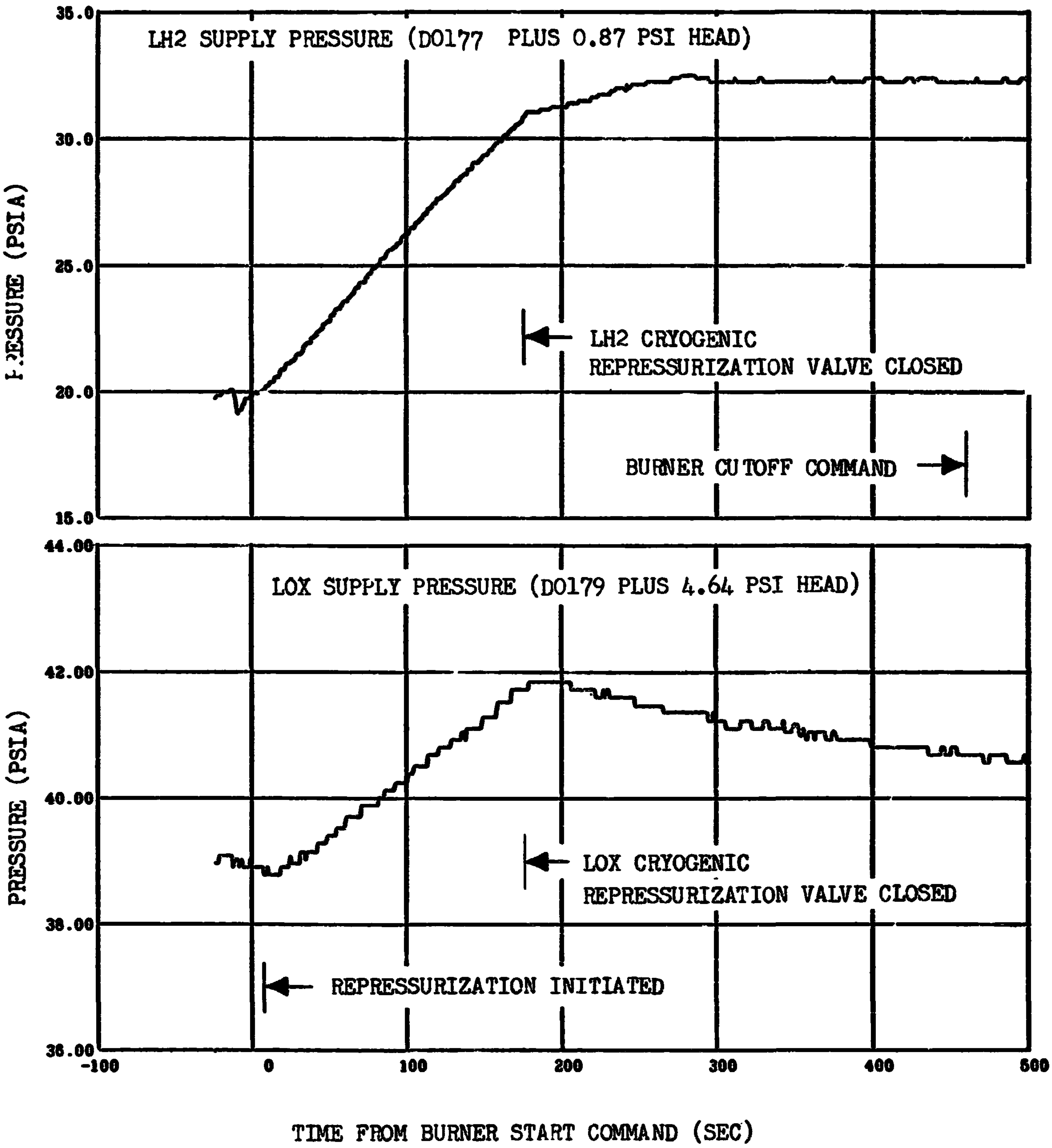


Figure 10-1. Burner Operation (Sheet 2 of 2)

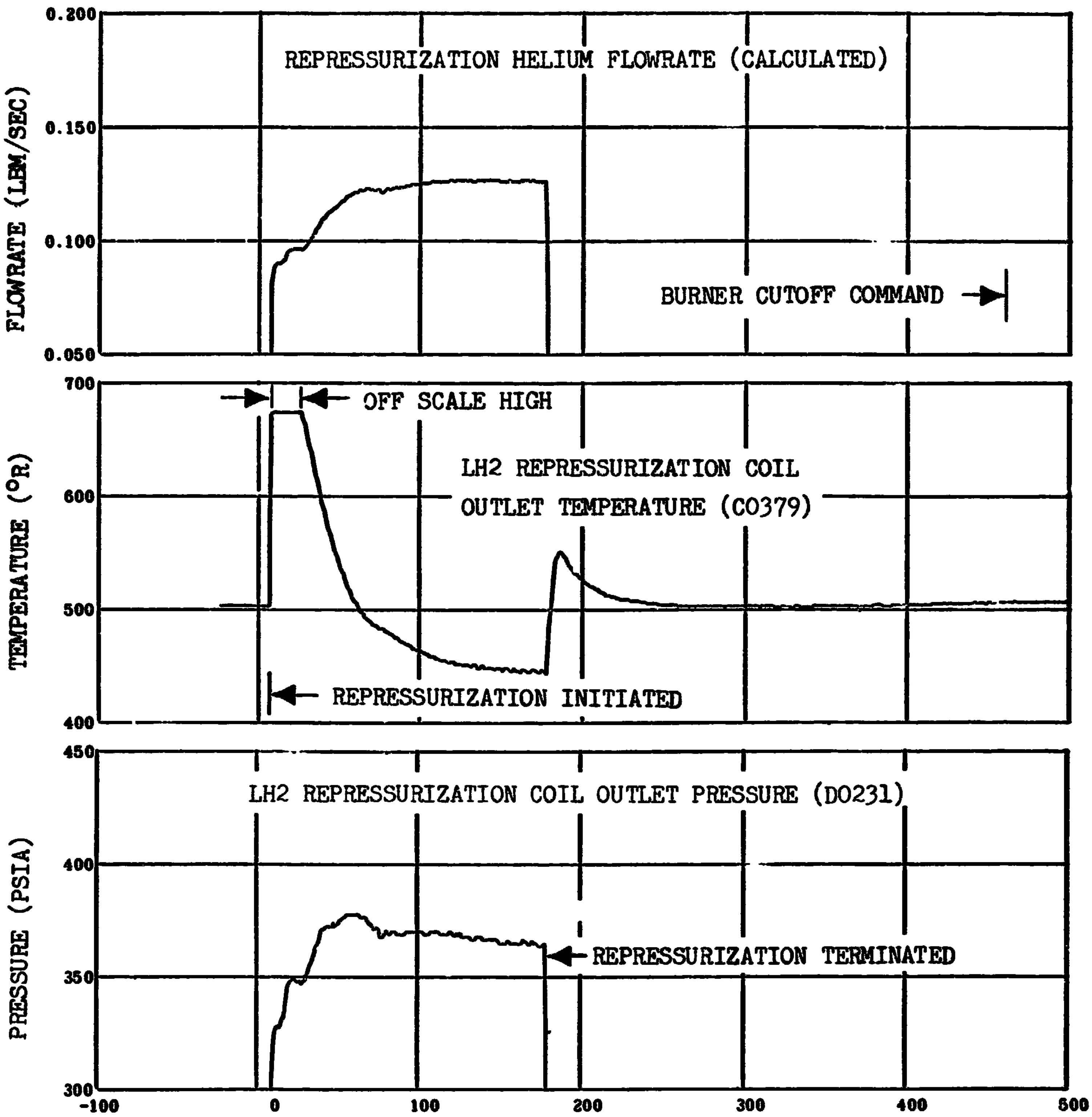


Figure 10-2. LH2 Tank O2-H2 Burner Repressurization

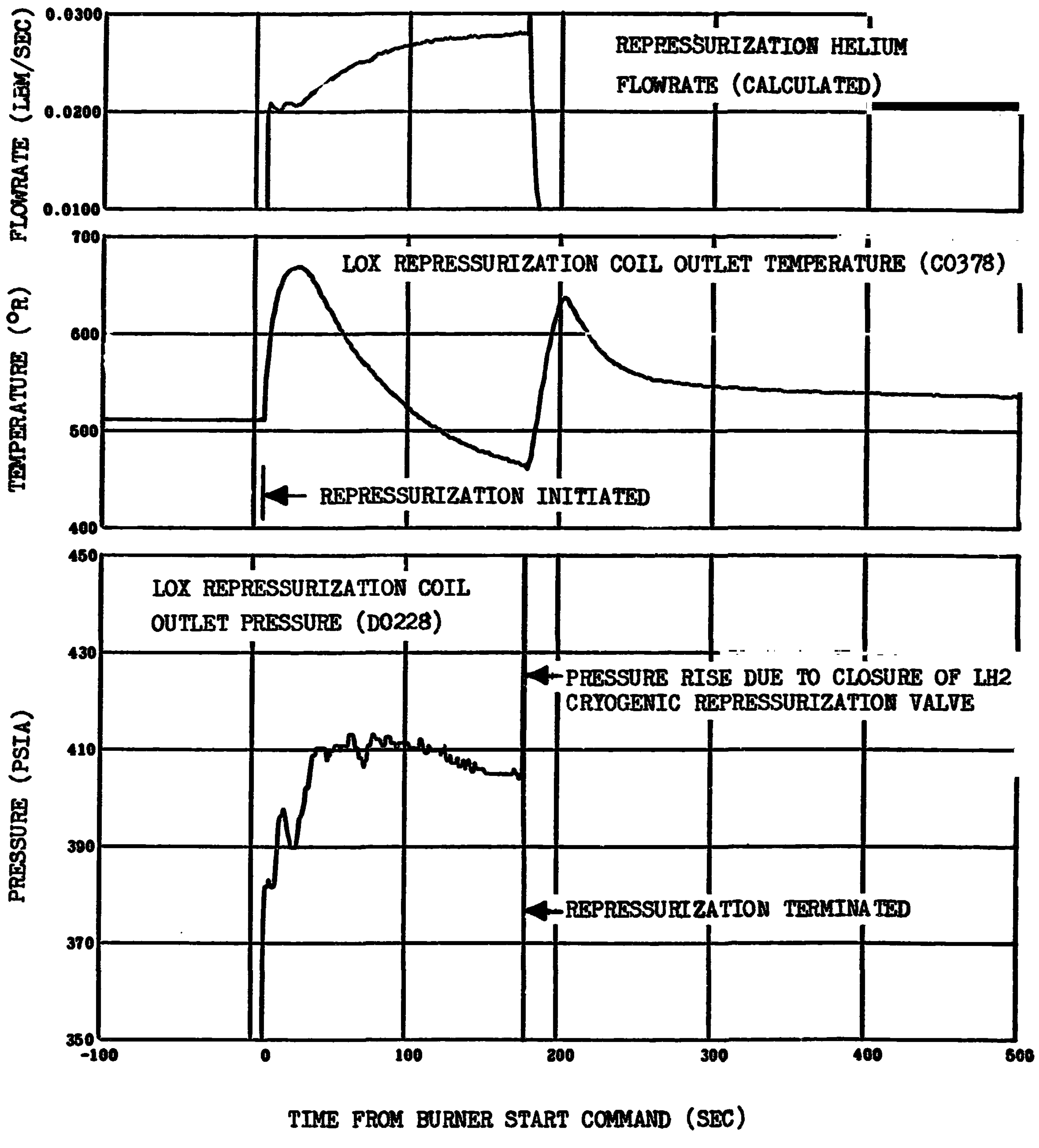


Figure 10-3. LOX Tank O2-H2 Burner Repressurization

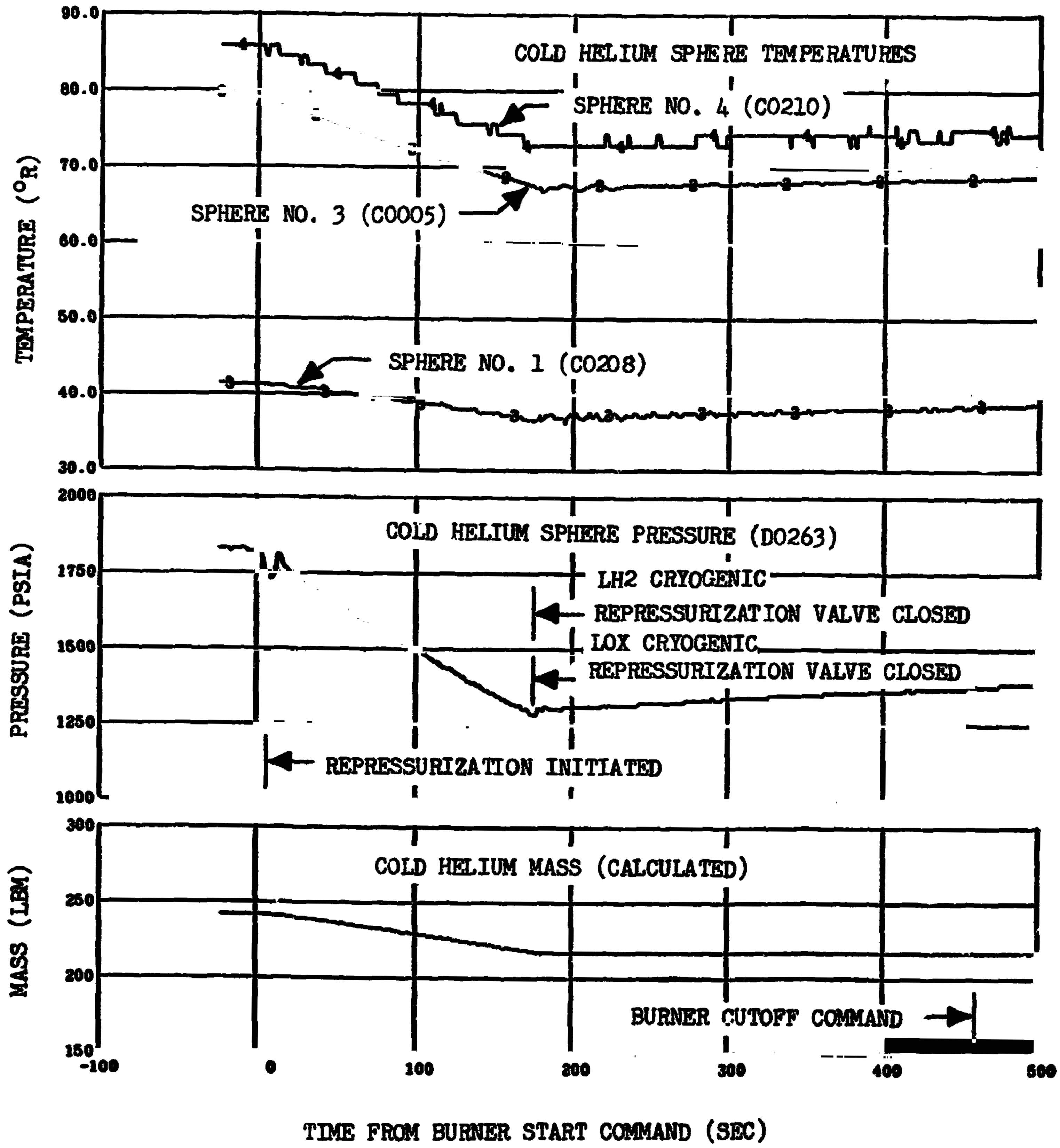


Figure 10-4. Cold Helium Sphere Conditions During O2-H2 Burner Operation

11. PROPELLANT UTILIZATION SYSTEM

The propellant utilization (PU) system generally performed satisfactorily during the acceptance firing, however, a minor anomaly with a sticky PU valve compromised the valve history. Propellant loading was successfully accomplished based upon a desired common propellant load of 193,273 lbm LOX and 38,000 lbm LH2. The LOX and LH2 masses obtained by the flow integral method were 191,619 lbm and 37,785 lbm, respectively. The PU indicated LOX and LH2 masses were 0.84 percent and 0.70 percent higher than the flow integral derived masses.

The PU indicated LOX mass was 0.02 percent less than the desired LOX loading and the PU indicated LH2 mass was 0.13 percent greater than the desired LH2 load. The LOX and LH2 full load masses, as determined by the volumetric method, were respectively, 0.78 percent greater and 0.74 percent greater than the flow integral method derived mass. Loaded mass as determined by the flow integral method was 0.86 percent and 0.57 percent lower than the desired load for LOX and LH2, respectively.

The PU system operated in a closed-loop mode for most of the single burn full duration firing. However, an open-loop excursion to the low EMR position (4.5:1.0) was commanded at 350.4 sec followed by a command to the null position (5.0:1.0) at 410.1 sec where it remained until cutoff. During the closed-loop operation a reference mixture ratio of 5.0:1.0 was utilized. Closed-loop valve cutback occurred 10.7 sec later than predicted. The steady-state valve position following the closed-loop cutback transient was approximately 0.6 deg higher than predicted.

The open-loop excursion resulted in an LH2 depletion cutoff. The resulting propellant masses at cutoff were 4.222 lbm LOX and 919 lbm LH2.

Engine thrust variation were well within the flight thrust variation limits derived for the Contract End Item (CEI) specification.

11.1 PU System Calibration

The nominal S-IVB-509 pre-acceptance mass sensor calibration data were determined from previous acceptance firing results.

The propellant mass at the upper and lower calibration point was determined from calculated unique tank volume data and predicted propellant densities. The capactiance at the lower end was determined from the vendor's sensor air capacitance and average fast drain data from previous acceptance firings.

The LOX sensor capacitance at the full immersion point was determined from the vendor's air capacitance and mean data accumulated from LOX sensor full immersion tests conducted on S-IVB-207, 208, 209, 503N, and 504N. The LH2 sensor capacitance at the upper calibration point was determined from the S-IVB-209, 504N, 505N, and 506 immersion test results and vendor's air capacitance.

The LOX and LH2 PU calibration data are presented in the following table:

PU MASS SENSOR	MASS (lbm)	CAPACITANCE (pf)	LOCATION
LOX	196,779	414.21	Top of inner element.
	1,316	282.12	Bottom of inner element.
LH2	44,714	1186.69	Top of inner element.
	206	972.52	Bottom of inner element.

11.2 PU Mass History

The flow integral, volumetric, and PU indicated methods were used to evaluate the acceptance firing propellant full load and mass history, however, only the flow integral method will be used to recalibrate the PU system for flight.

The flow integral method consists of determining the mass flowrate of LOX and LH2 and integrating as a function of time to obtain total consumed mass during firing. Flow integral mass values are based on the analysis of engine flowmeter data, thrust chamber pressure, engine influence equations, and engine tag values.

The initial full load mass, using the flow integral method, is determined by adding the propellant residuals at engine cutoff, the fuel pressurant added to the ullage, and propellants lost to boiloff to the total mass consumed.

The PU volumetric masses were derived from raw PU probe output data computed according to volumetric calibration slopes and volumetric nonlinearities. The calibration slopes (lbm/pf) were computed from capacitance propellant mass relationships at the upper and lower probe active element extremities. The propellant mass at these extremities was calculated from unique tank volume determined from task measurements and propellant density.

The PU indicated method measures propellant mass from the raw PU probe output.

Table 11-1 presents the propellant mass history for salient times during the acceptance firing.

11.2.1 Propellant Loading

Propellant loading was accomplished automatically by the loading computer. Desired, indicated, volumetric, and flow integral full propellant loads at ESC are presented in table 11-1.

The deviation between the desired and flow integral masses were within 0.86 percent and 0.57 percent for LOX and LH2 respectively.

11.2.2 Propellant Residuals

Propellant residuals were computed at Engine Cutoff Command (ECC) using both the PU mass sensors and the residual point level sensors. Three level sensors in each tank (L0017, L0018, and L0019 in the LH2 tank, and L0014, L0015, and L0016 in the LOX tank) were activated during the firing and were used for residual analysis.

Level sensor residuals were computed using the engine consumption data (G105 program) to extrapolate from level sensor activation to engine cutoff. A statistical average residual was computed for the point level sensors for each propellant tank. The final residual masses at engine cutoff are the weighted average residuals of the point level sensor and PU mass sensor residual data.

Table 11-2 contains a tabulation of PU volumetric, level sensor, and weighted average data. The residuals as determined from the weighted average data were 4,222 lbm and 919 lbm for LOX and LH2, respectively.

11.2.3 PU Efficiency

PU efficiency is determined by expressing the usable residual propellants at depletion as a percentage of the total propellant load. The planned residuals were not optimized to include the effects of the open-loop demonstration. Total stage propellant consumption rates (determined by engine and stage flowrate evaluation) at engine cutoff were 387.8 lbm/sec for LOX and 78.6 lbm/sec for LH2.

The combined PU efficiency (open- and closed-loop) was 99.82 percent. The planned usable residuals were 2,512 lbm of LOX and 0 lbm of LH2. The actual extrapolated residuals result with no remaining usable LH2 and 2918 lbm usable LOX remaining.

Actual LH2 depletion would have occurred at ECC +2.023 sec.

11.3 PU System Response

PU system closed-loop mixture ratio valve cutback occurred at 196.7 sec which was 6.7 sec later than the predicted cutback time of 190.0 sec. Following valve cutback the actual valve history settled at a steady-state valve position which was approximately [illegible] higher than predicted.

The 4.5 EMR ON command was given at ESC +450.0 sec, with PU valve movement noticed 0.8 sec later. The PU valve took 2.4 sec to travel from the 5.0 EMR position to the 4.5 EMR position, which was about 1.2 sec longer than expected. This increased time to reach the low EMR stop indicates that the LOX flow torque on the PU valve was greater than expected. Slewing of the valve to the 5.5 EMR position at PU activate was normal which indicates that the PU electronic assembly and PU motor were operating normal. No sticking of the PU valve was noticed prior to the 4.5 EMR ON command. The 4.5 EMR OFF command was given at 410.0 sec with PU valve movement noticed 0.4 sec later. Return to the 5.0 EMR position was within 1.0 sec which is as predicted. This indicated that the PU system was operating normal and that the PU valve was not sticking.

Operation for the remainder of the burn was at the 5.0 EMR position. The PU valve level was approximately 1.0 deg higher than predicted indicating higher flow torques than expected.

A reconstruction of the PU valve history was not made, however, the cutback time deviations and valve position shift during the transient have been determined using flow integral results.

The following table summarizes the deviations between the actual and predicted PU valve position histories based upon the flow integral results utilizing the G105 program.

DESCRIPTION	CUTBACK TIME DEVIATION (sec)	VALVE POSITION SHIFT (deg)
Loading	+7.0	0
Calibration (G-105)	-7.5	-1.0
Tank/Sensor Mismatch (G-105)	+9.0	+0.3
Tag Valves and Engine Environment (G-105)	+8.0	+1.0
Valve Flow Torque	0	+6.0
Total	+3.5	+1.3

The summation of deviations listed in the above table would increase the predicted cutback time by 3.5 sec and increase the mean value of mixture ratio valve position by 1.3 deg.

11.3.1 PU Cutback Deviations

11.3.1.1 Loading Computer Deviation

Loading computer deviations are the difference between the PU system indicated loads at ESC and the desired PU system indicated loads at ESC. The loading deviations were -41 lbm LOX (-0.021 percent) and +48 lbm LH2 (+.125 percent). These deviations were within acceptable loading errors of +3.0 percent. The combined effect of these loading computer deviations decreased cutback time by 7.0 sec. The mean level of the valve position after cutback was not affected by these loading computer deviations.

11.3.1.2 Flow Integral Mass/Capacitance Calibration Deviation

Calibration deviations are the difference between PU indicated loads and flow integral loads during burn. Calibration deviations at ESC were +0.861 percent LOX and +0.705 percent LH2. Calibration deviations at ECC were +0.010 percent LOX and +0.003 percent LH2. The slope deviations between ESC and ECC were +0.851 percent LOX and +0.702 percent LH2. The desired reference mixture ratio (RMR) for the S-IVB-509 acceptance firing was 5.0:1.0. The bridge gain ratio (BGR) was also calibrated at 5.0:1. Since PU sensor calibration deviations also affect the BGR, the actual ratio was 4.99:1. The calibration deviations decreased the cutback time by 7.5 sec and shifted the mean value of valve position by -1.0 deg.

11.3.1.3 Tank/Sensor Mismatch

The effect of the differences between the average of previous acceptance firing flow integral tank-to-sensor mismatch results for the S-IVB-509 prediction and the actual flow integral mismatch increased cutback by 9.0 sec and raised the mean level of valve position by 0.3 deg. Figures 11-4 and 11-5 show the actual flow integral LOX and LH2 nonlinearities with the sensor manufacturing nonlinearities included.

11.3.1.4 Tag Values and Engine Environment

The effect of the difference between predicted and actual engine tag valves and engine environment was to increase cutback time by 8.0 sec and to raise the mean level of valve position by 1 degree.

11.3.1.5 Valve Flow Torque

The observed difference between predicted and actual PU valve position during 5.0 EMR open-loop operation was assumed to be flow torque displacement and was also assumed to be present during 5.0 EMR closed-loop operation. This amounts to approximately +1.0 deg of valve displacement. No deviation in cutback time was used since there is very little flow torque on the PU valve at the 5.5 EMR position.

TABLE 11-1
PROPELLANT MASS HISTORY

EVENT		DESIRED MASS (lbm)	PU INDICATED MASS (lbm)	PU VOLUMETRIC MASS (lbm)	FLOW INTEGRAL MASS (lbm)	DEVIATION FROM FLOW INTEGRAL MASS					
						DESIRED		PU INDICATED		VOLUMETRIC	
SIMULATED LIFTOFF (TO) AND ENGINE START COMMAND	LOX	193,273	193,232	193,107	191,619	+1654	0.86%	+1613	0.84%	+1488	0.78%
	LH2	38,000	38,048	38,066	37,785	+215	0.57%	+263	0.70%	+281	0.74%
	TOTAL	231,273	231,280	231,173	229,404	+1869	0.84%	+1876	0.82%	+1769	0.77%
PU VALVE CUTBACK (ESC +196.7 SEC)	LOX	105,320	105,769	105,494	104,530	+790	0.41%	+1239	0.65%	+964	0.50%
	LH2	21,830	21,741	21,700	21,642	+188	0.50%	+99	0.26%	+58	0.15%
	TOTAL	127,150	127,510	127,194	126,172	+978	0.43%	+1338	0.58%	+1022	0.45%
ENGINE CUTOFF COMMAND	LOX	4,664*	4,274	4,224	4,222	+442	0.23%	+52	0.03%	+2	0
	LH2	1,116*	930	940	919	+197	0.52%	+11	0.03%	+21	0.06%
	TOTAL	5,780*	5,204	5,164	5,141	+639	0.28%	+63	0.03%	+23	0.01%

*Corrected to actual cutoff time.

TABLE 11-2
PROPELLANT RESIDUAL SUMMARY

	LEVEL SENSOR (ACTIVATION TIME)							
	LOX TANK				LH2 TANK			
	L0016 (To +934.386)	L0015 (To +949.385)	L0014 (To +966.217)	ECC (To +966.315)	L0019 (To +934.886)	L0018 (To +043.219)	L0017 (To +960.468)	ECC (To +966.315)
PU VOLUMETRIC	16,600	10,716	4,260	4,224	3,387	2,727	1,394	940
LEVEL SENSOR INDICATED VALUE	16,690	10,654	4,294		3,404	2,743	1,366	
LEVEL SENSOR EXTRAPOLATED RESIDUAL	4,305	4,091	4,256	4,221*	932	927	906	917*
WEIGHTED AVERAGE RESIDUAL				4,222** $\pm$198				919**

NOTE: To = 14:00:48.00.0
*Statistical average of level sensor residuals
**Statistical average of level sensor and PU system residuals

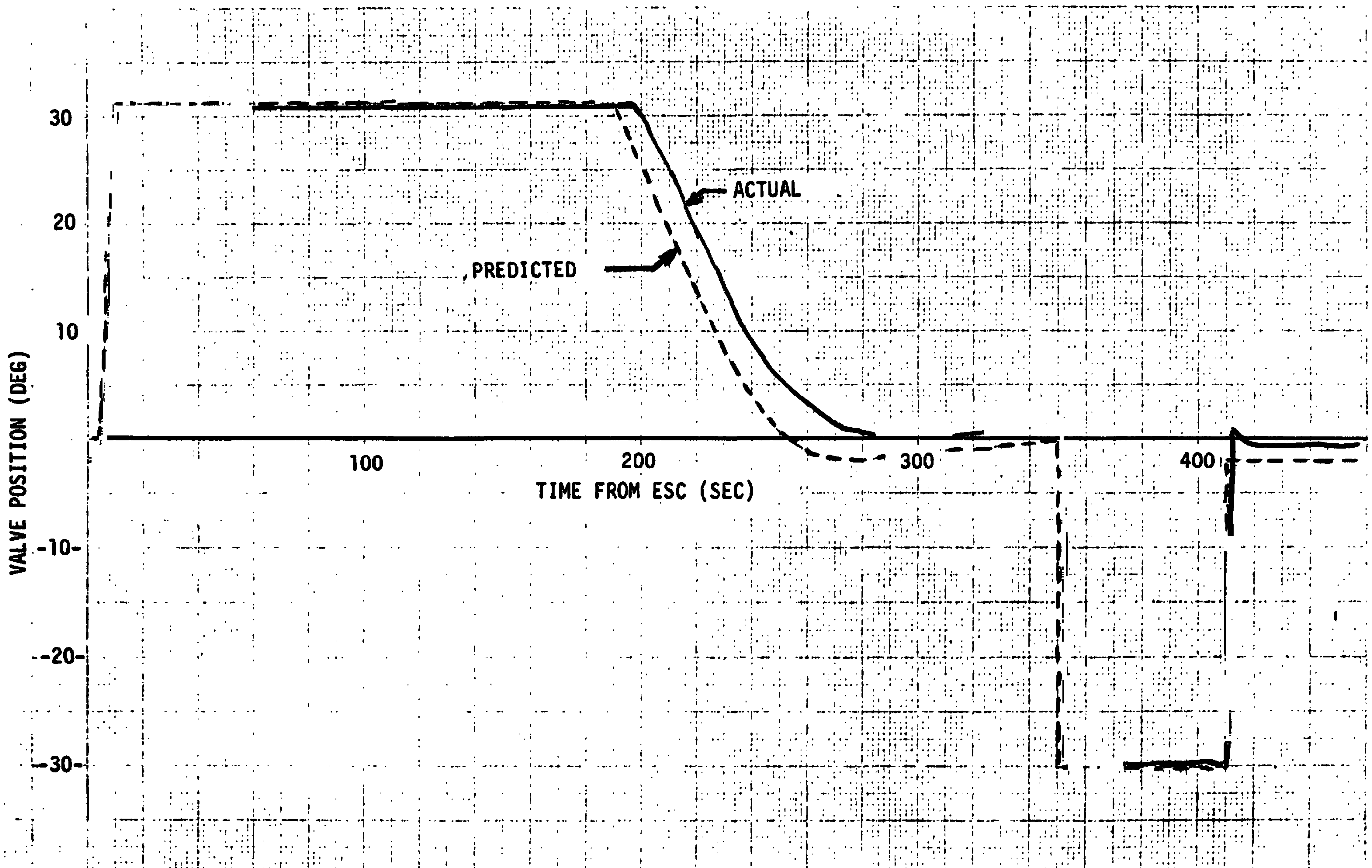


Figure 11-1. PU Valve Response

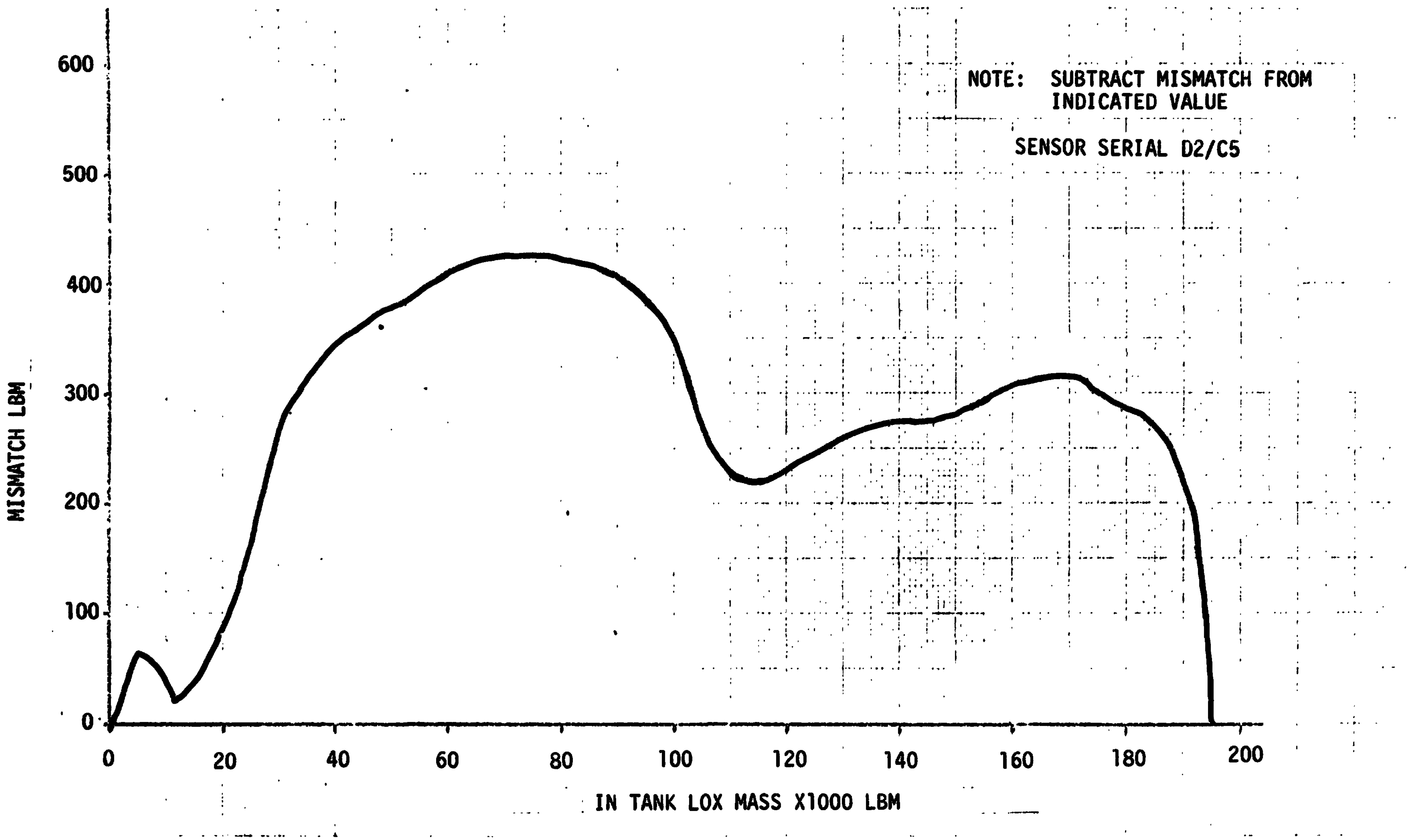


Figure 11-2. LOX Tank to Sensor Mismatch, Volumetric Method

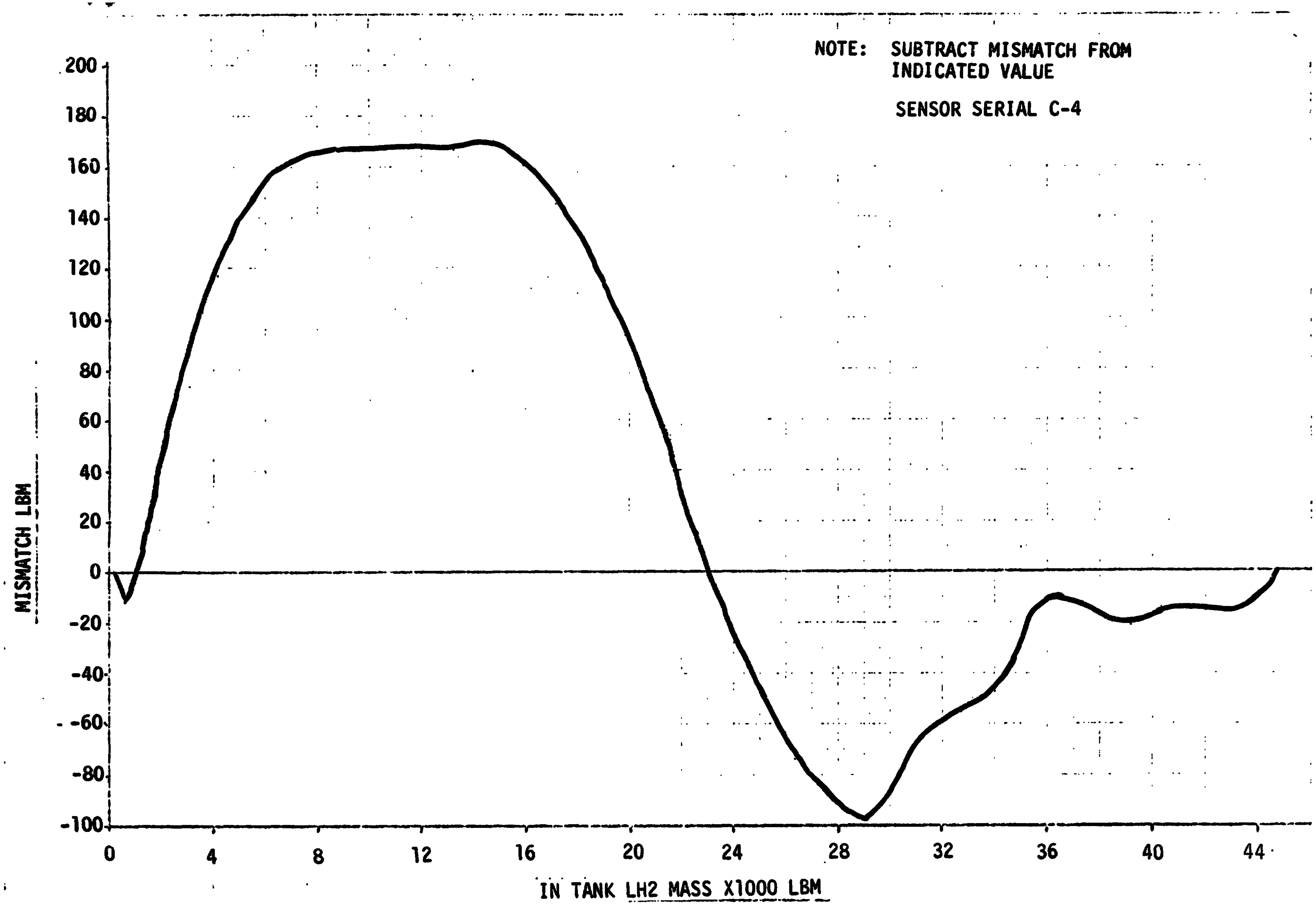


Figure 11-3. LH2 Tank to Sensor Mismatch, Volumetric Method

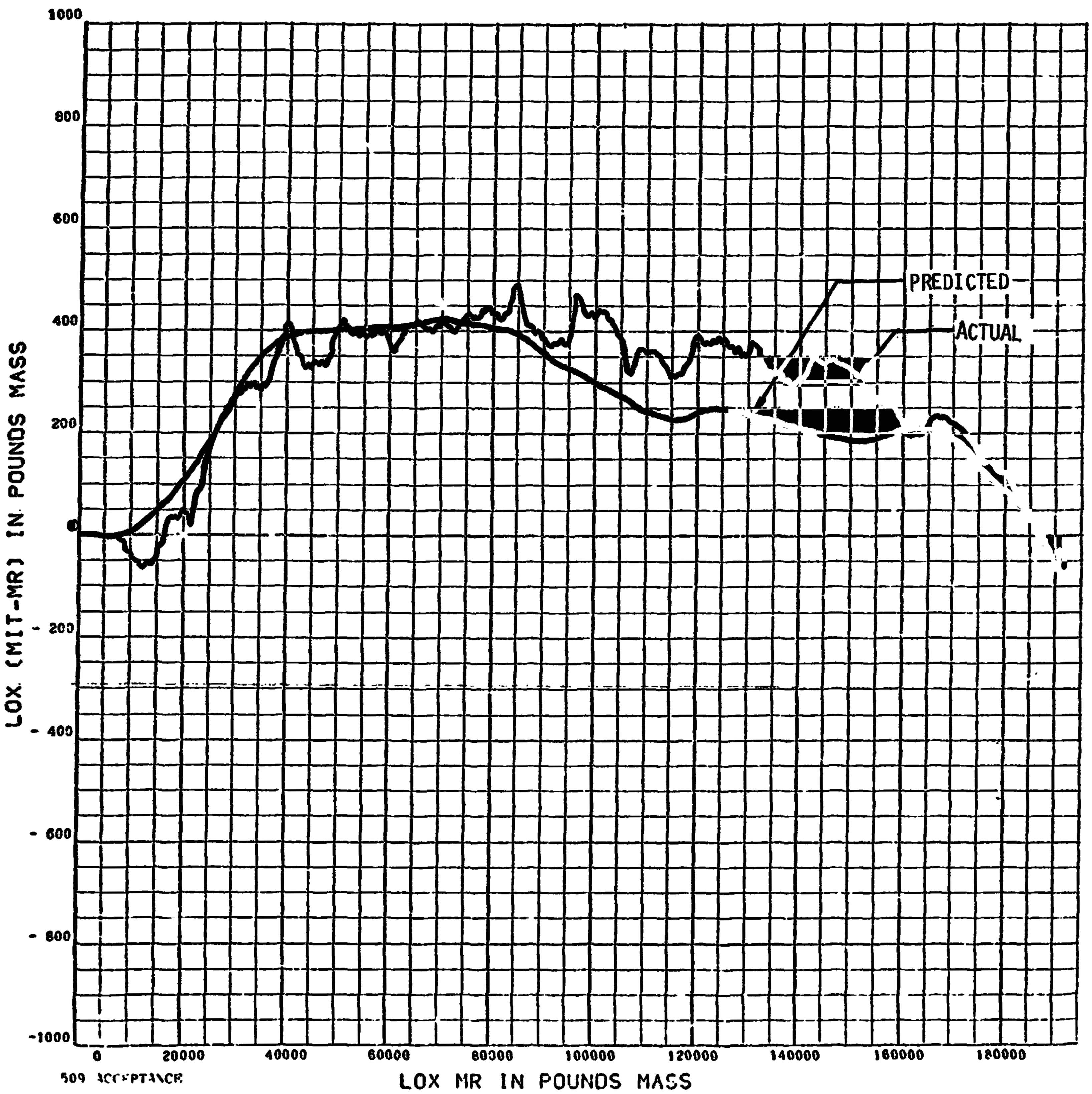


Figure 11-4. LOX Normalized Probe Linearity (Flow Integral Method)

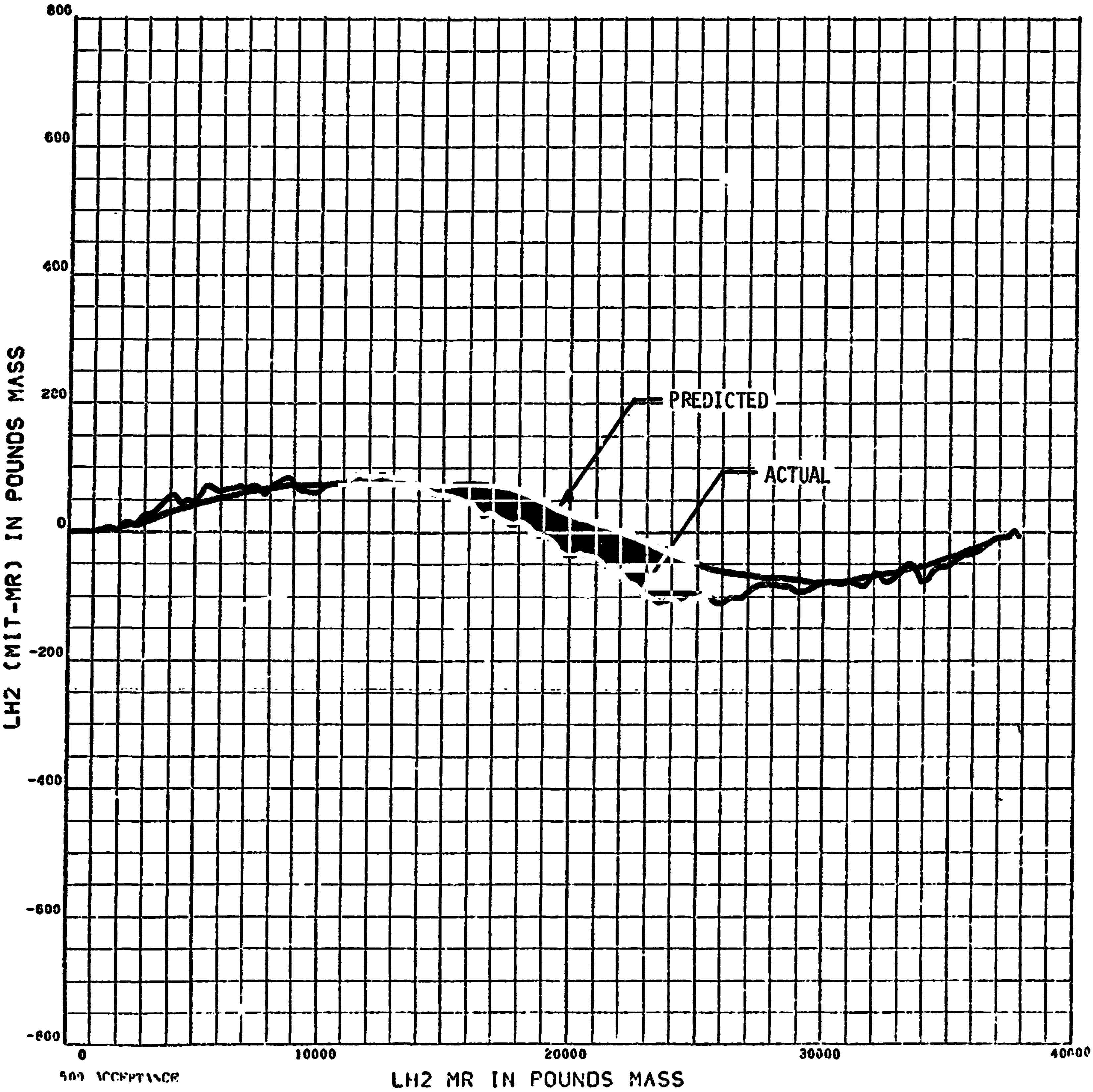


Figure 11-5. LH2 Normalized Probe Linearity (Flow Integral Method)

12. DATA ACQUISITION SYSTEM

The data acquisition system demonstrated competency in acquiring stage information, conditioning the data signals, translating these signals into proper telemetry format, and transmitting the telemetry information to a ground station. The measurements which comprise this system are specified in Douglas Drawing No. 1B43574 Change G AEO H, J and K, Instrumentation Program and Components List (IP&CL); however, not all measurements specified in the IP&CL were in operation during this test. The system demonstrated that it was free of radio frequency interference and was electromagnetically compatible with other stage systems.

The performance of the data acquisition system was satisfactory throughout the O_2-H_2 burner and mainstage firing phases of the acceptance firing. The reduced data from all channels were acceptable with the exception of the discrepancies described in tables 12-1 and 12-2.

The following is a summary of the telemetry data measurement system performance during acceptance firing:

Total number of measurements assigned	279
Total number of measurements deleted	52
Total number of active measurements	227
Measurement failures	2
Total acceptable measurements	225
Measurement efficiency	99.1 percent
Measurement discrepancies	5

12.1 Instrumentation Subsystem Performance

The instrumentation system performed satisfactorily during all phases of the acceptance firing. Two measurement failures were observed and five measurements exhibited data problems. Table 12-2 lists these measurements and elaborates their malfunction characteristics. Table 12-3 lists the measurements that were inactive.

Measurements M0031-411, Voltage Firing Unit 2 E.B.W. Range Safety; N0062-411, Miscellaneous Secure Range Safety Receiver 2 Low Level Signal Strength and K0142-411, Event-Range Safety 2 Pulse Sensor were qualified as good even though Range Safety Number 2 failed to operate during the acceptance firing. Posttest checkout revealed the problem to be a faulty decoder in the Range Safety 2 system. This unit was replaced and documented on FARR (Failure and Rejection Report) Tag 500-816-252.

The measurements listed below were susceptible to the high RF field experienced on the Complex Beta test stands. The RFI condition was exhibited as a data shift when comparing open and closed loop TM data. RFI responses have been observed during previous firings; this problem does not exist when the stage is in the launch vehicle configuration. No action is being contemplated to remedy the situation.

M0060-411	Volt	-	PU Valve Control
N0018-411	Misc.	-	PCM/FM Transmitter Output Power
N0055-411	Misc.	-	Telemetry RF System Reflected Power, Channel 1

RACS calibrations were evaluated for proper levels at T - 2207 seconds (1324:01 hours PDT) of Phase D (Mainstage firing). All measurements were within the acceptable RACS levels.

Comparison of the T/M and GIS hardwire data was conducted during the Sacramento test facility evaluation. A total of 37 measurements was compared with satisfactory results. The comparison results are shown in table 12-4.

12.2 Telemetry Subsystem Performance

The telemetry subsystem performance was good. There was no loss of system synchronization, and good data were received from all channels. DDAS hardwire (600Hz) to T/M (open loop RF) comparison did not reveal any vehicle data discrepancies.

Response of the telemetry subsystem to in-flight multiplexer calibrations were evaluated during phase D at T_0 + 116 seconds. The childdown pumps and the auxiliary hydraulic pump were operating at T_0 + 116 seconds. All calibration levels during the evaluation period were within the tolerance of ± 8 bit counts of a range of 24 to 999 bits.

12.3 RF Subsystem Performance

The RF subsystem performance was satisfactory. During open-loop operation the RF power measurements were susceptible to the RF field; therefore, proper assessment of the RF system could not be accomplished. For worst case using the closed-loop power output and the open-loop reflected power, the PCM/FM VSWR was 1.75:1.

The following table presents the PCM/FM transmitter output power and VSWR data for open- and closed-loop operation.

RF Subsystem Data

System	Open-Loop Value*	Closed-Loop Value
PCM/FM Transmitter Output Power (minimum acceptable is 15 W)	22.6 watts	20.8 watts
VSWR (maximum acceptable is 1.8:1)	1.72:1	1.46:1

*RF measurements were susceptible to RFI

12.4 Electromagnetic Compatibility

The data acquisition system did not interfere with other stage systems in the areas of electromagnetic compatibility. However, five measurements did exhibit data shift or noise spikes. See tables 12-2, Telemetry Measurement Anomalies, and 12-6, Hardwire Measurement Discrepancies for a complete listing of EMC anomalies.

12.5 Emergency Detection System Measurements

Measurements D0177-408 (Press - LH_2 Tank Ullage, EDS No. 1), D0178-408 (Press - LH_2 Tank Ullage, EDS No. 2), D0179-406 (Press - LOX Tank Ullage EDS No. 1), and D0180-406 (Press - LOX Tank Ullage, EDS No. 2) all performed satisfactorily.

12.6 Hardwire Data Acquisition System Performance

The ground instrumentation system (GIS) provides a backup and data comparison for certain stage telemetry system parameters in addition to recording measurements from the ground support and facility equipment.

The GIS also provides stripcharts for redline and cutoff-parameter monitoring. The GIS performance during acceptance firing was satisfactory.

The following table presents the type of recording equipment and the number of channels used.

Ground Recorder		Channels Assigned
Beckman 210 Digital Data System		141
Constant Bandwidth FM		55
Wideband FM		7
GSE Event		658
Stripcharts		39
	Total	900

Table 12-5 presents a list of the various types of measurement data recorded and the performance of the system.

12.6.1 Hardwire Measurement Discrepancies

There were six measurement failures, yielding an overall hardwire measurement efficiency of 99.5 percent. Measurement discrepancies that occurred during the acceptance firing are listed in table 12-6.

TABLE 12-1

TELEMETRY SYSTEM PERFORMANCE SUMMARY

FUNCTION	NUMBER ASSIGNED PER IP&CL	INACTIVE**	NET ACTIVE	DISCREPANCIES	FAILURES	PERFORMANCE* (percent)
Acceleration (A)	0	-	-	-	-	-
Acoustic (B)	0	-	-	-	-	-
Temperature (C)	61	16	45	1	1	97.7
Pressure (D)	79	24	55	2	0	100.0
Vibration (E)	0	-	-	-	-	-
Flow (F)	4	0	4	0	0	100.0
Position (G)	8	5	3	0	0	100.0
Events (K)	71	4	67	1	0	100.0
Liquid Level (L)	7	1	6	0	0	100.0
Volt/Current/Freq (M)	38	2	36	0	1	97.2
Miscellaneous (N)	9	0	9	1	0	100.0
Strain (S)	0	-	-	-	-	-
Speed (T)	2	0	2	0	0	100.0
TOTAL	279	52	227	5	2	99.1 percent

$$\text{*Performance (percent)} = \frac{\text{Net Active - Failures}}{\text{Net Active}} \times 100$$

**See Table 12-3 T/M Measurement Status

TABLE 12-2

TELEMETRY MEASUREMENT ANOMALIES

MEASUREMENT NUMBER	PARAMETER	REMARKS
C0001-401	Temp - Fuel Turbine Inlet	The transducer output became erratic at T + 547 seconds into the J-2 engine burn phase. At T + 913 seconds, it went offscale high and remained there until 23 seconds after engine cutoff, when it returned on-scale. Postfiring RAC calibration levels were within acceptable tolerance. The transducer was removed and returned to Rocketdyne for testing. A replacement probe has been installed.
C0052-428	Temp - Fuel Tank Position 1	While immersed in LH_2, the sensor indicated 1.2 degrees warmer temperature than was expected. A thorough investigation of the measurement system was made with no problem being evident. The anomaly is not uncommon in this type of narrow-ranged measurement. This shift is compensated for during the data reduction process and valid data are recovered. Replacement of the transducer and signal conditioning equipment is no guarantee the measurement would perform differently. The only reliable checkout would require an LH_2 loading. The anomaly was documented on FARR (Failure and Rejection Report) Tag 500-816-694, and was bought off as acceptable to Engineering.
D0014-403	Pressure - Control Helium Regulator Discharge	During the J-2 engine firing period, the measurement exhibited noise while at the operating pressure. This noise was most prevalent at about 470 to 500 psia. Postfire investigation disclosed a high contact resistance existing between the wiper arm and the potentiometer in the 450 to 500 psia range. The transducer was replaced.

TABLE 12-2 (Continued)

TELEMETRY MEASUREMENT ANOMALIES

MEASUREMENT NUMBER	PARAMETER	REMARKS
D0055-424	Pressure - Oxidizer Tank Inlet	A negative data dropout was noted on this measurement after J-2 engine firing cutoff. The dropout was approximately 0.3 second duration. A 2 per cent negative shift in data level was noted after the dropout. The transducer was removed for testing, and subsequently replaced.
M0042-404	Freq - 5-Volt Excitation Module Aft	The measurement indicated an offscale high condition throughout the J-2 engine firing sequence. The problem was isolated to the frequency-to-dc converter unit. The unit does not function properly at lower temperatures. It was removed from the stage and replaced.
K0128-404	Event - Switch Selector Output Monitor	A 0.864-Volt pulse of approximately 5 milliseconds duration occurred 11 milliseconds after the Low Temperature 1 and 2 Simulate Commands were removed during the O_2-H_2 burner voting circuit test. This pulse is attributed to the transformer action of the collapsing field of the mag-latch relay units in the O_2-H_2 burner shutdown circuit, and contributes no system degradation or malfunction.
M0060-411	Volt - PU Valve Control	This measurement indicated a shift in data level of + 1 per cent when the RF system was switched from open- to closed-loop operation. The data shift is within the system EMI criteria.

TABLE 12-2 (Continued)

TELEMETRY MEASUREMENT ANOMALIES

MEASUREMENT NUMBER	PARAMETER	REMARKS
N0018-411 N0055-411	Misc - PCM/FM Transmitter Output Misc - T/M RF System Reflected Power	These measurements were susceptible to the high RF environment experienced on the Beta test stand. Data shifts were observed when the RF system was switched from open- to closed-loop operation. N0055-411 shifted minus 2.1 per cent while N0018-411 shifted minus 6 per cent. RFI responses have been observed during previous firings; this problem does not exist when the stage is in the launch vehicle configuration.

TABLE 12-3
INACTIVE MEASUREMENTS

MEASUREMENT NO.	PARAMETER	REMARKS
*C0003-403	Temp - Fuel Pump Inlet	C0003-403 was connected to element "B" of the dual element probe in place of C0648, equivalent hardwire measurement, to provide greater accuracy in center of flow for redline monitoring.
C0021-415	Temp - Attitude Control Fuel Module 2	Simulated, APS not installed
C0022-415	Temp - Attitude Control Oxid Module 2	Simulated, APS not installed
C0023-414	Temp - APS Helium Pressure Tank, Module 1	Simulated, APS not installed
C0050-401	Temp - Hydraulic Pump Inlet Oil	Open, H/W requirement
C0102-411	Temp - Forward Battery No. 1	Simulated, primary battery not used
C0103-411	Temp - Forward Battery No. 2	Simulated, primary battery not used
C0104-404	Temp - Aft Battery No. 1	Simulated, primary battery not used
C0105-404	Temp - Aft Battery No. 2	Simulated, primary battery not used
C0131-404	Temp - Aft Battery No. 1, Unit 2	Simulated, primary battery not used
C0132-414	Temp - Attitude Control Oxid, Module 1	Simulated, APS not installed
C0136-414	Temp - Attitude Control Fuel, Module 1	Simulated, APS not installed
C0187-415	Temp - APS Helium Press Tank Module 2	Simulated, APS not installed
C-0211-411	Temp - Fwd Battery No. 1, Unit 2	Simulated, primary battery not used
C0212-404	Temp - Aft Battery No. 2, Unit 2	Simulated, primary battery not used
C0382-403	Temp - GOX/GH_2 Burner Chamber Dome	Open, H/W requirement

*This measurement installed in variance to IP&CL configuration

TABLE 12-3 (Continued)

MEASUREMENT NO.	PARAMETER	REMARKS
D0027-414	Press - Attitude Control, Chamber 1-1	Simulated, APS not installed
D0028-414	Press - Attitude Control, Chamber 1-2	Simulated, APS not installed
D0029-414	Press - Attitude Control, Chamber 1-3	Simulated, APS not installed
D0030-415	Press - Attitude Control, Chamber 2-1	Simulated, APS not installed
D0031-415	Press - Attitude Control, Chamber 2-2	Simulated, APS not installed
D0032-415	Press - Attitude Control, Chamber 2-3	Simulated, APS not installed
D0035-414	Press - Attitude Control, Helium Pressure Tank 1	Simulated, APS not installed
D0036-415	Press - Attitude Control, Helium Pressure Tank 2	Simulated, APS not installed
D0037-414	Press - Helium Reg. Outlet, Module 1 (APS)	Simulated, APS not installed
D0038-415	Press - Helium Reg. Outlet, Module 2 (APS)	Simulated, APS not installed
D0041-403	Press - Hydraulic System	Open, H/W requirement
D0042-403	Press - Reservoir Oil	Open, H/W requirement
D0070-414	Press - Fuel Supply Manifold, Module 1	Simulated, APS not installed
D0071-414	Press - Oxid Supply Manifold, Module 1	Simulated, APS not installed
D0072-415	Press - Fuel Supply Manifold, Module 2	Simulated, APS not installed
D0073-415	Press - Oxid Supply Manifold, Module 2	Simulated, APS not installed
D0097-414	Press - Fuel Tank Ullage Volume, Module 1	Simulated, APS not installed

TABLE 12-3 (Continued)

MEASUREMENT NO.	PARAMETER	REMARKS
D0098-414	Press - Oxid Tank Ullage Volume, Module 1	Simulated, APS not installed
D0099-415	Press - Oxid Tank Ullage Volume, Module 2	Simulated, APS not installed
D0100-415	Press - Fuel Tank Ullage Volume, Module 2	Simulated, APS not installed
D0220-414	Press - Ullage Control, Chamber 1-4	Simulated, APS not installed
D0221-415	Press - Ullage Control, Chamber 2-4	Simulated, APS not installed
D0250-414	Press - Attitude Control Helium Press, Tk 1	Simulated, APS not installed
D0251-415	Press - Attitude Control Helium Press, Tk 2	Simulated, APS not installed
G0003-401	Position, Main Oxid Valve	Simulated, H/W requirement
G0004-401	Position, Main Fuel Valve	Simulated, H/W Requirement
G0005-401	Position - Gas Generator Valve	Simulated, H/W requirement
G0008-401	Position - Oxid Turbine Bypass Valve	Simulated, H/W requirement
G0009-401	Position - GH_2 Start Tank Valve	Simulated, H/W requirement
K0020-401	Event - ASI LOX Valve Open	Open, computer requirement
K0126-401	Event - Oxid Bleed Valve Closed	Open, computer requirement
K0127-404	Event - Fuel Bleed Valve Closed	Open, computer requirement
K0152-404	Event - Rate Gyro Wheel Speed OK Indication	Simulated, rate gyro not installed
L0007-403	Level - Reservoir Oil	Simulated, H/W requirement
M0073-404	Voltage - Helium Heater Spark Exciter - [illegible]	Open, computer requirement
M0074-404	Voltage - Helium Heater Spark Exciter - 1	Open, computer requirement

TABLE 12-3 (Continued)

MEASUREMENT NO.	PARAMETER	REMARKS
M0019	Current Load Fwd Bat 1	Due to a dual grounding configuration when in the battery simulate mode, the four battery currents are trend data only.
M0020	Current Load Fwd Bat 2	
M0021	Current Load Aft Bat 1	
M0022	Current Load Aft Bat 2	

TABLE 12-4

TELEMETRY TO HARDWIRE DATA COMPARISON (T_0 +574 sec)

PARAMETER	UNITS	TELEMETRY		HARDWIRE		
		MEAS NO.	PCM	MEAS NO.	GIS	F/M
Temp - LH_2 Pump Inlet	deg R	C0003	37.7	C0658	37.6	37.5
Temp - LOX Pump Inlet	deg R	C0004	164.5	C0659	164.5	164.4
Temp - GH_2 Start Bottle	deg R	C0006	206	C0649	213	--
Temp - LOX Pump Discharge	deg R	C0133	169.6	C0648	169.6	169.4
Temp - LH_2 Pump Discharge	deg R	C0134	51.5	C0644	51.5	51.4
Temp - Thrust Chamber Jacket	deg R	C0199	141	C0645	139	--
Press - Thrust Chamber	psia	D0001	790	D0524	789	--
Press - LH_2 Pump Inlet	psia	D0002	30.4	D0536	30.7	31.7
Press - LOX Pump Inlet	psia	D0003	42.7	D0537	42.7	42.7
Press - LH_2 Pump Discharge	psia	D0008	1,223	D0516	1,231	1,230
Press - LOX Pump Discharge	psia	D0009	1,071	D0522	1,060	1,050
Press - Control Helium Reg. Discharge	psia	D0014	482	D0581	480	495
Press - GH_2 Start Bottle	psia	D0017	1,187	D0525	1,179	1,185
Press - Engine Reg. Outlet	psia	D0018	419	D0535	408	--
Press - Engine Control He Sphere	psia	D0019	2,865	D0534	2,845	--
Press - LH_2 Repress Sphere	psia	D0020	2,910	D0513	2,905	--
Press - LOX Repress Sphere	psia	D0088	2,885	D0512	2,900	--
Press - LH_2 Tank Ullage EDS 1	psia	D0177	31.6	D0539	31.9	--
Press - LH_2 Tank Ullage EDS 2	psia	D0178	32.4	D0539	31.9	--
Press - LOX Tank Ullage EDS 1	psia	D0179	38.9	D0540	39.4	--
Press - LOX Tank Ullage EDS 2	psia	D0180	39.1	D0540	39.4	--
Press - Ambient Helium Sphere	psia	D0236	2,859	D0541	2,896	--
Press - Common Bulkhead Internal	psia	D0237	0.0	D0545	0.0	--
Press - Cold Helium Sphere	psia	D0261	2,164	D0542	2,199	--
Flowrate - LOX	gpm	F0001	2,884	F0506	2,874	2,876
Flowrate - LH_2	gpm	F0002	7,993	F0507	7,938	7,931
Position - Pitch Actuator	deg	G0001	0.0	G0504	0.0	-0.1
Position - Yaw Actuator	deg	G0002	0.1	G0505	0.1	0.0
Position - PU Valve	deg	G0010	30.8	G0503	30.9	31.0

TABLE 12-4 (Continued)

PARAMETER	UNITS	TELEMETRY		HARDWIRE		
		MEAS NO.	PCM	MEAS NO.	GIS	F/M
Voltage - Engine Control Bus	Vdc	M0006	28.0	M0514	27.8	28.0
Voltage - Engine Ignition Bus	Vdc	M0007	28.2	M0515	28.1	28.3
Voltage - Aft Battery 1	Vdc	M0014	27.5	M0541	28.0	28.0
Voltage - Aft Battery 2	Vdc	M0015	55.8	M0540	55.6	56.0
Voltage - Fwd Battery 1	Vdc	M0016	27.9	M0543	28.1	28.5
Voltage - Fwd Battery 2	Vdc	M0018	27.3	M0542	27.9	28.0
Speed - LOX Pump	rpm	T0001	8,589	T0502	8,631	8,620
Speed - LH_2 Pump	rpm	T0002	26,980	T0503	26,992	26,990

TABLE 12-5

HARDWIRE DATA ACQUISITION SYSTEM

MEASUREMENT TYPE	RECORDED	DISCREPANCIES*	SUCCESSFUL (percent)
Pressure	94	1	98.9
Temperature	25	0	100.0
Flow	2	0	100.0
Position	10	0	100.0
Voltage-Current	32	0	100.0
Events	658	4	99.4
Speed	2	0	100.0
Level	1	0	100.0
Vibration	5	1	80.0
Miscellaneous	2	0	100.0
TOTAL	831	6	99.3 percent

*A data discrepancy does not necessarily mean that no data were gathered for this measurement. Refer to table 12-6 for a description of the problem

TABLE 12-6

HARDWIRE MEASUREMENT DISCREPANCIES

Measurement Number	Parameter	Remarks
D0521-401	Pressure - Oxidizer Pump Primary Seal Cavity	The transducer indicated a minus 8 percent offset approximately 24 seconds after J-2 Engine start. Postfire check of the transducer verified that it had shifted. A replacement will be installed prior to the next acceptance firing.
E707-B03	Vibration - Engine Safety Cutoff No. 1	High output spikes on the data throughout the J-2 Engine firing phase were caused by a faulty accelerometer cable. The cable assembly and transducer were replaced.
K0561-410 K2442-404	Event - LH2 Directional Vent Valve Ground Position Event - Ambient Helium Supply Valve Closed Relay Reset	The invalid cycles on these event measurements were caused by the range time code being superimposed on the Digital Events Recorders (DER) data channel. This was caused by a faulty AGC card in the time code translator. The problem also caused many errors on the DER time printouts, which have been corrected manually on the qualified data. The faulty AGC was replaced.
K0608-408	Event - LH2 Not Overfill Indication	Invalid cycles occurred on this measurement in unison with switch selector commands PU mixture ratio 4.5 to 1 on (SW Sel 17) and PU program mixture ratio off (SW Sel 18). This is an EMC anomaly, but contributed no system degradation or malfunction, and further investigation or corrective action is not anticipated.
K0675-404	Event - LOX Fast Fill Sensor Wet Indication	This measurement did not indicate properly during LOX loading, and cycled 14 times during the acceptance firing. The sensor was removed, while still on the instrumentation probe, and the unit was immersed in cryogenics and allowed to chill. The failure mode was repeated and found to be caused by a loose connector. The connector was tightened and the unit was reinstalled.

13. ELECTRICAL POWER AND CONTROL SYSTEMS

13.1 Electrical Power System

The electrical power system performed satisfactorily throughout the acceptance firing. It supplied power to other stage systems, as required, and the external/internal motor-driven switches functioned properly.

13.1.1 Battery Simulators

Model DSV-4B-134 Power Supplies were used to provide electrical power during the acceptance firing test. The power supply voltage and current levels were measured at the Stage Battery Simulators, Model DSV-4B-727, and these levels remained within their required limits. Figures 13-1 through 13-8 are plots showing the voltage and current levels at the battery simulators during selected phases of the acceptance firing test.

13.1.2 PU Static Inverter-Converter

The static inverter-converter operated satisfactorily during the O_2-H_2 burner repressurization test and the mainstage firing test. Voltage and frequency levels during the acceptance firing test are given below.

Measurements and Characteristics	Acceptable Limits	Actual Min. Value	Actual Max. Value
M0001-411 Voltage	115.0 ±3.45 Vrms	114.2 Vrms	114.3 Vrms
M0004-411 Voltage	4.9 ±0.2 Vdc	5.02 Vdc	5.02 Vdc
M0023-411 Voltage	21.0 $^{+1.5}_{-1.0}$ Vdc	21.86 Vdc	21.87 Vdc
M0012-411 Frequency	400.0 ±6.0 Hz	400.7 Hz	400.8 Hz

13.1.3 Chilldown Inverters

The inverters performed satisfactorily during the mainstage firing test and the O_2-H_2 burner repressurization test. The phase voltages and frequencies are listed on the following page.

Measurements and Characteristics	Acceptable Limits	Actual Min. Value	Actual Max. Value
M0027-404 Phase A-B, LOX C/D Inverter	56 ±4 Vac	55.1 Vac	55.7 Vac
M0040-404 Phase A-C, LOX C/D Inverter	56 ±4 Vac	55.5 Vac	55.9 Vac
M0029-404 Frequency LOX C/D Inverter	400 ±10 Hz	400.2 Hz	401.2 Hz
M0026-404 Phase A-B, LH_2 C/D Inverter	56 ±4 Vac	55.4 Vac	55.9 Vac
M0041-404 Phase A-C, LH_2 C/D Inverter	56 ±4 Vac	55.5 Vac	56.0 Vac
M0028-404 Frequency LH_2 C/D Inverter	400 ±10 Hz	400.7 Hz	401.6 Hz

13.1.4 5-Volt Excitation Modules

The forward and aft 5-volt excitation modules performed as expected during the acceptance firing test. The actual performance values are shown below:

Measurements and Characteristics	Acceptable Limits	Actual Min. Value	Actual Max. Value
M0025-404 Aft Voltage	5.0 ±0.03 Vdc	5.01 Vdc	5.02 Vdc
M0024-411 Forward 1 Voltage	5.0 ±0.03 Vdc	5.00 Vdc	5.00 Vdc
M0068-411 Forward 2 Voltage	5.0 ±0.03 Vdc	5.00 Vdc	5.01 Vdc
M0042-404 Frequency 5-volt Excitation Module, Aft	2000 ±200 Hz	Frequency out of tolerance, see table 12-2 for problem description	
M0043-404 Frequency 5-volt Excitation Module, Fwd	2000 ±200 Hz	2026	2029

13.2 Electrical Control System

The operational integrity of the electrical control system was verified through the evaluation of the sequence-of-events records from the digital events recorder (DER) and the PCM flight-measurement events data (section 5). The switch selector and sequencer operated properly in sending all control commands to the stage, and all of the commands were received in the stage.

13.2.1 J-2 Engine Control System

All measurements verified that the engine control system responded properly to the engine start and cutoff commands. The sequence of events (section 5) lists the engine firing events and response times.

13.2.2 Secure Range Safety Command System

The secure range safety command system was tested during the engine-burn phase to verify the capability of engine cutoff and propellant dispersion. Range Safety System 1 operated as expected. Evaluation of the data verified that the arm and engine cutoff (ECO) and propellant dispersion (P/D) commands were received, and that the EBW firing unit (F/U) discharged into its pulse sensor. Range Safety System 2 failed to operate during the test. The problem was thought to be due to a faulty decoder. A Failure and Rejection Report (FARR) tag was written against the decoder (FARR tag #500-816-252). The decoder has been removed for testing and has been replaced.

The following measurements were used to evaluate system performance:

K0141-411	Event - R/S 1 EBW Pulse Sensor Indication
K0142-411	Event - R/S 2 EBW Pulse Sensor Indication
*K0650-411	Event - P/D EBW F/U 1 Power On
*K0651-411	Event - P/D EBW F/U 2 Power On
*K0659-411	Event - R/S 2 Arm and ECO Command Received
*K0660-411	Event - R/S 1 Arm and ECO Command Received
*K0678-411	Event - R/S 2 Receiver Power On
*K0679-411	Event - R/S System 2 Off Command Received
*K0680-411	Event - R/S 1 Receiver Power On
*K0681-411	Event - R/S 1 Off Command Received
*K0692-404	Event - R/S 2 EBW Arm and Cutoff Command On
*K0693-404	Event - R/S 1 EBW Arm and Cutoff Command On
M0030-411	Volts - R/S 1 EBW Firing Unit
M0031-411	Volts - R/S 2 EBW Firing Unit

*Hardwire Measurement

N0057-411	Misc - R/S 1 Low Level Signal Strength
N0062-411	Misc - R/S 2 Low Level Signal Strength
*K5757-B03	Event - R/S Propellant Dispersion Command
*K5758-B03	Event - R/S EBW F/U Arm and ECO Command
*K5759-B03	Event - R/S System Off Command
K2404-411	Event - R/S 1 Propellant Dispersion Command Received
K2405-411	Event - R/S 2 Propellant Dispersion Command Received

13.2.3 Control Pressure Switches

A review of the event and pressure measurements associated with the following pressure switches verified that each switch functioned properly during the acceptance firing test. Following is a list of the measurements used for each respective pressure switch verification.

a. LOX Tank Ground Fill Valve Control, Prepress, Flight Control, and Repress Pressure Switch

K0102-404	Event - LOX Prepress and Flight Control Switch - Energized
*K0563-404	Event - LOX Prepress and Flight Control Switch - Energized
K0108-404	Event - LOX Prepress Flight Switch - De-energized
D0179-406	Pressure - LOX Tank Ullage EDS 1
D0180-406	Pressure - LOX Tank Ullage EDS 2
*K0571-404	Event - Cold He SOV Energized - Indication
*K0444-403	Event - LOX Tank Repress Valve - Energized

b. LOX Tank Repress Regulator Backup Pressure Switch

*K0444-403	Event - LOX Tank Repress Valve - Energized
D0228-403	Pressure - LOX/LH_2 Burner LOX Press Coil

c. LH_2 Tank Repress Regulator Backup Pressure Switch

*K0443-403	Event - LH_2 Tank Repress Valve - Energized
D0231-403	Pressure - GOX/GH_2 Burner LH_2 Press Coil

*Hardwire Measurement

d. Control (Ambient) Helium Regulator Backup Pressure Switch

D0014-403	Pressure - Control Helium Regulator, Discharge

e. LH_2 Ground Fill Valve Control, Prepress, Flight Control, and Step-Pressure Switch

K0184-404	Event - LH_2 Flight Control Pressure Switch - Energized
*K0616-404	Event - LH_2 Tank Prepressurization Pressure Switch - Energized
K0101-404	Event - LH_2 Repress Control Switch - De-energized
*K0582-404	Event - LH_2 Tank Repress Pressure Switch - On
*K0524-404	Event - LH_2 Tank Flight Pressure Valve - Energized
*K0523-404	Event - LH_2 Tank Step-Pressure Valve - Energized
D0177-408	Pressure - LH_2 Tank Ullage EDS 1
D0178-408	Pressure - LH_2 Tank Ullage EDS 2

f. LH_2 Tank Repress Pressure Switch

K0101-404	Event - LH_2 Repress Control Switch - De-energized
*K0582-404	Event - LH_2 Tank Repress Pressure Switch - On
*K0443-403	Event - LH_2 Tank Repress Valve - Energized
D0177-408	Pressure - LH_2 Tank Ullage EDS 1
D0178-408	Pressure - LH_2 Tank Ullage EDS 2

g. Engine Pump Purge Control Module Pressure Switch

K0105-40	Event - Pump Purge Regulator Backup - Deenergized
*K0456-404	Event - Seal Pump Purge Control Regulator Backup Pressure Switch - Deenergized
*K0566-404	Event - Engine Pump Purge Control Module Solenoid Valve - Energized
D0050-403	Pressure - Engine Pump Purge Regulator Pressure

*Hardwire Measurement

h. LOX Tank Regulator Backup Pressure Switch

K0156-404	Event - LOX Tank Regulator Backup Pressure Switch - Energized
*K0571-404	Event - LOX Tank Cold He SOV Energized - Indication
D0105-403	Pressure - LOX Tank Pressurization Module He Gas

13.2.4 Control Valves

a. LH_2 and LOX Vent Valves

The following measurements verified the satisfactory operation of the LOX and LH_2 Tank Vent Valves, the LH_2 Tank Directional Valve, the LOX Tank NPV Valve, and the LH_2 Tank Latch and Relief Valve:

K0001-410; *K0532-410	Event - Fuel Tank Vent Valve 1 - Closed
K0017-410; *K0542-410	Event - Fuel Tank Vent Valve 1 - Open
K0002-424; *K0533-424	Event - Oxid. Tank Vent Valve 1 - Closed
K0016-404; *K0543-404	Event - Oxid. Tank Vent Valve 1 - Open
K0113-411	Event - LH_2 Tank Directional Vent Valve C - Closed
K0114-411	Event - LH_2 Tank Directional Vent Valve D - Closed
K0198-424; *K0465-424	Event - LOX Tank NPV Valve Open
K0199-424; *K0466-424	Event - LOX Tank NPV Valve Closed
K0210-410; *K2431-410	Event - LH_2 Tank Latch and Relief Valve Closed
K0211-410; *K2429-410	Event - LH_2 Tank Latch and Relief Valve Open

b. Chilldown Shutoff Valves

The LOX and LH_2 chilldown shutoff valves responded properly to commands, as verified by the following measurements:

K0136-409; *K0551-409	Event - LH_2 Chilldown Shutoff Valve - Closed
K0137-409; *K0544-409	Event - LH_2 Chilldown Shutoff Valve - Open Talkback

*Hardwire Measurement

K0139-424; *K0552-424	Event - LOX Chilldown Shutoff Valve - Closed
K0138-424; *K0545-424	Event - LOX Chilldown Shutoff Valve - Open Talkback

c. Fill and Drain Valves (Fuel and LOX)

A review of the following events showed that the LOX and LH_2 fill and drain valves operated according to the GSE commands issued.

K0003-427; *K05[illegible]-404	Event - LH_2 Tank Fill and Drain Valve - Closed
*K0546-404	Event - LH_2 Tank Fill and Drain Valve - Open Talkback
K0003-427; *K0553-404	Event - LOX Tank Fill and Drain Valve - Closed
*K0547-404	Event - LOX Tank Fill and Drain Valve - Open Talkback

d. LOX and LH_2 Prevalves

The proper operation of the LOX and LH_2 prevalves was verified by an evaluation of the following events:

K0109-403; *K0541-403	Event - LOX Prevalve - Open
K0110-403; *K0550-403	Event - LOX Prevalve - Closed
K0111-404; *K0540-404	Event - LH_2 Prevalve - Open
K0112-404; *K0549-404	Event - LH_2 Prevalve - Closed

13.2.5 Depletion Sensors

A review of the following measurements showed that the LOX and LH_2 depletion sensors performed satisfactorily, and no anomalies were observed during the test:

*K0601-406	Event - LOX Depletion Sensor No. 1 - Wet
*K0602-406	Event - LOX Depletion Sensor No. 2 - Wet
*K0603-406	Event - LOX Depletion Sensor No. 3 - Wet
*K0449-404	Event - LOX Depletion Sensor No. 4 - Wet
*K0597-408	Event - LH_2 Depletion Sensor No. 1 - Wet
*K0598-408	Event - LH_2 Depletion Sensor No. 2 - Wet
*K0599-408	Event - LH_2 Depletion Sensor No. 3 - Wet
*K0450-411	Event - LH_2 Depletion Sensor No. 4 - Wet

*Hardwire Measurement

13.3 Auxiliary Propulsion System (APS) Electrical Control System

The APS simulators, Model DSV-4B-188B, are used during the acceptance firing to verify the APS-stage interface control functions. The remaining measurements that were evaluated and the results are listed below:

		Min Value (Vdc)	Max Value (Vdc)
K0132-404	Event - APS Eng. 1-1/1-3 Feed Valves Open	3.70	3.75
K0134-404	Event - APS Eng. 2-1/2-3 Feed Valves Open	3.70	3.80
K0133-404	Event - APS Eng. 1-2 Feed Valves Open	3.75	3.85
K0135-404	Event - APS Eng. 2-2 Feed Valves Open	3.80	3.80

A minimum value of 3.2 Vdc indicates that the feed valves are operating according to commands.

13.4 Ullage Rocket Exploding Bridgewire (EBW) System

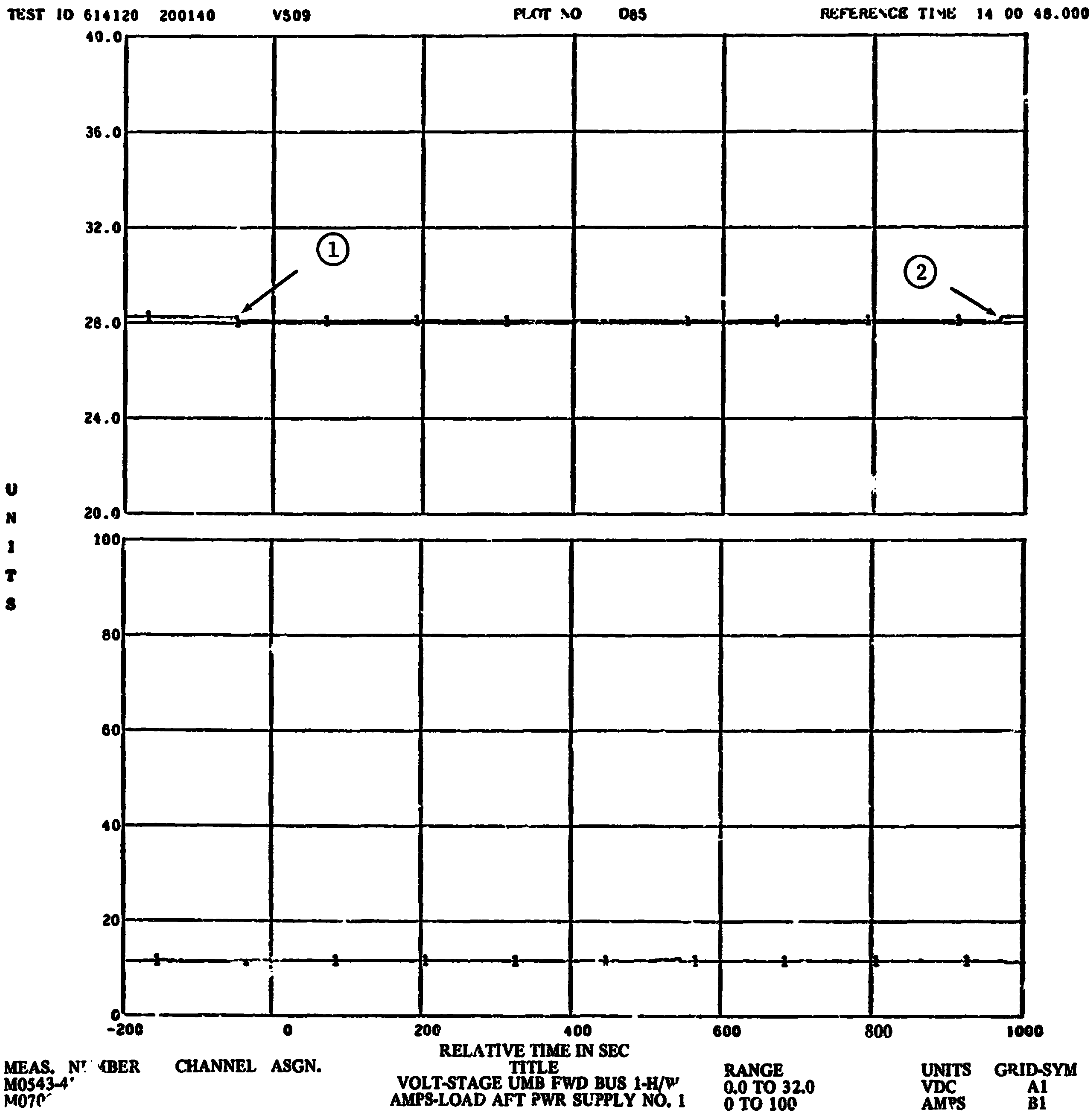
Since live ordnance is not installed, EBW pulse sensors are used during the acceptance firing to verify the operational integrity of the stage electrical control system in providing the commands necessary to charge, fire, and jettision the ullage rockets. The measurements given below furnished the data used to verify this integrity:

K0149-404	Event - Ullage Rocket Jettison EBW P/S 1 Indication
K0150-404	Event - Ullage Rocket Jettison EBW P/S 2 Indication
K0176-404	Event - Ullage Rocket Ignition EBW P/S 1 Indication
K0177-404	Event - Ullage Rocket Ignition EBW P/S 2 Indication
*K0673-404	Event - Ullage Rocket Pilot Relays Reset
M0064-404	Volts - Ullage Rocket Ignition, EBW F/U 1
M0065-404	Volts - Ullage Rocket Ignition, EBW F/U 2
M0067-404	Volts - Ullage Rocket Jettison, EBW F/U 1
M0068-411	Volts - Ullage Rocket Jettison, EBW F/U 2

*Hardware Measurement

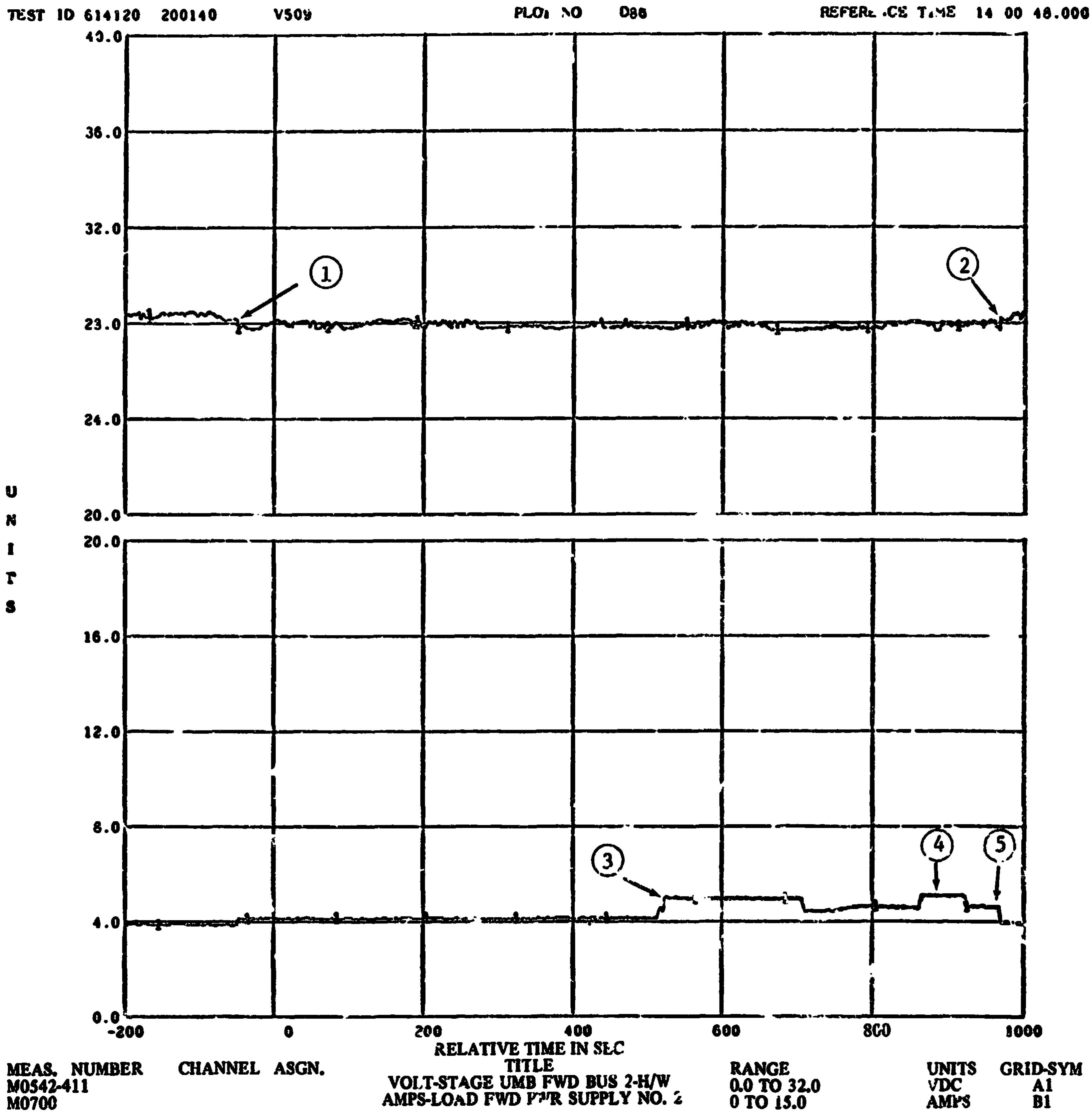
13.5 O_2-H_2 Burner

The operation of the O_2-H_2 burner, with respect to the operational integrity of the electrical control system, was normal, and no problems were encountered. The sequence of events (section 5) verifies that burner-control commands were sent and received, and that instrumentation response and talkback signals occurred as predicted. The voltage and current profiles of the battery simulators during the burner firings are presented in figures 13-5, 13-6, 13-7, and 13-8.



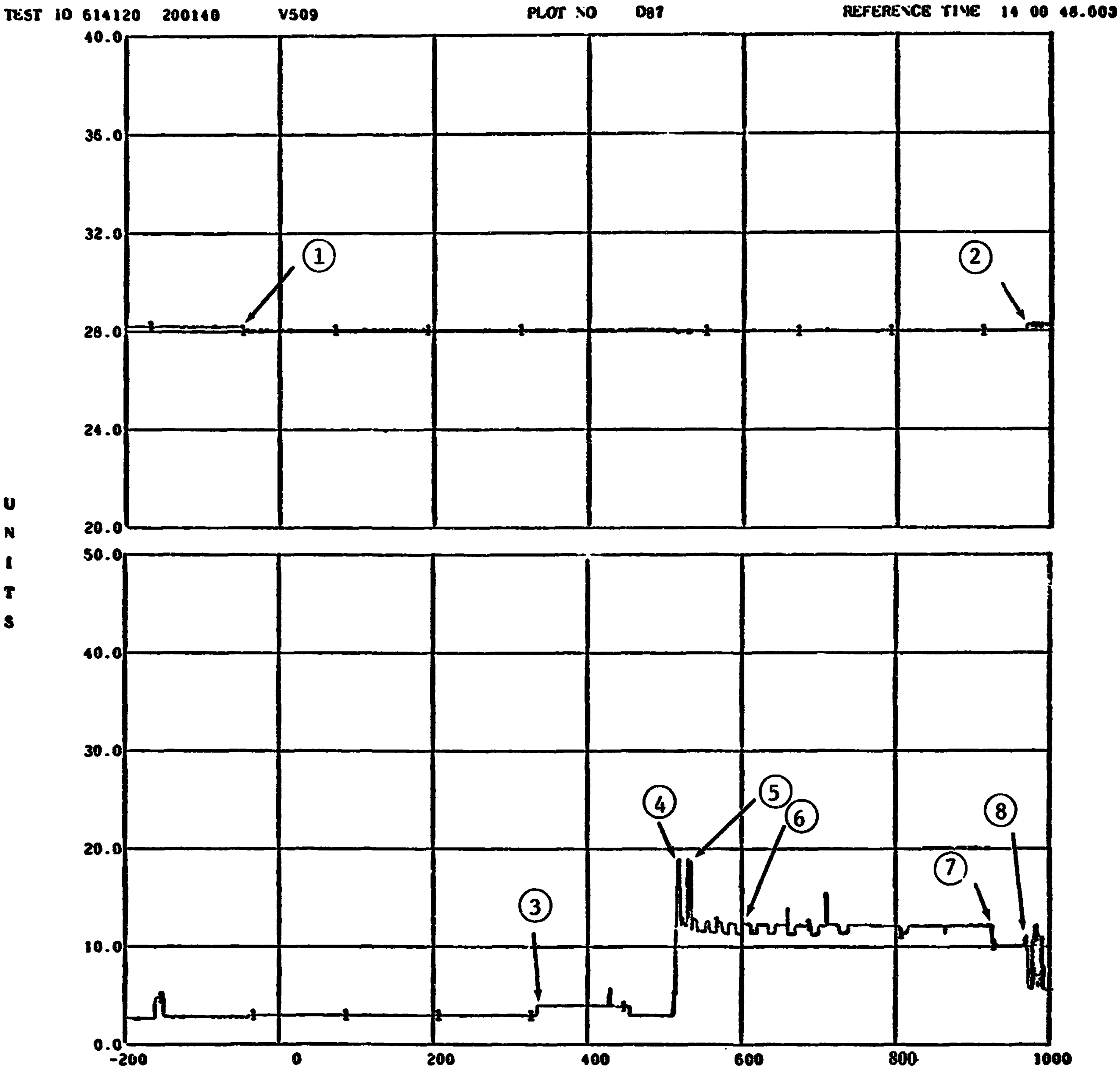
1 External/Internal Power Transfer
2 Internal/External Power Transfer

Figure 13-1. Forward Bus No. 1 Profile -- Main Engine Firing



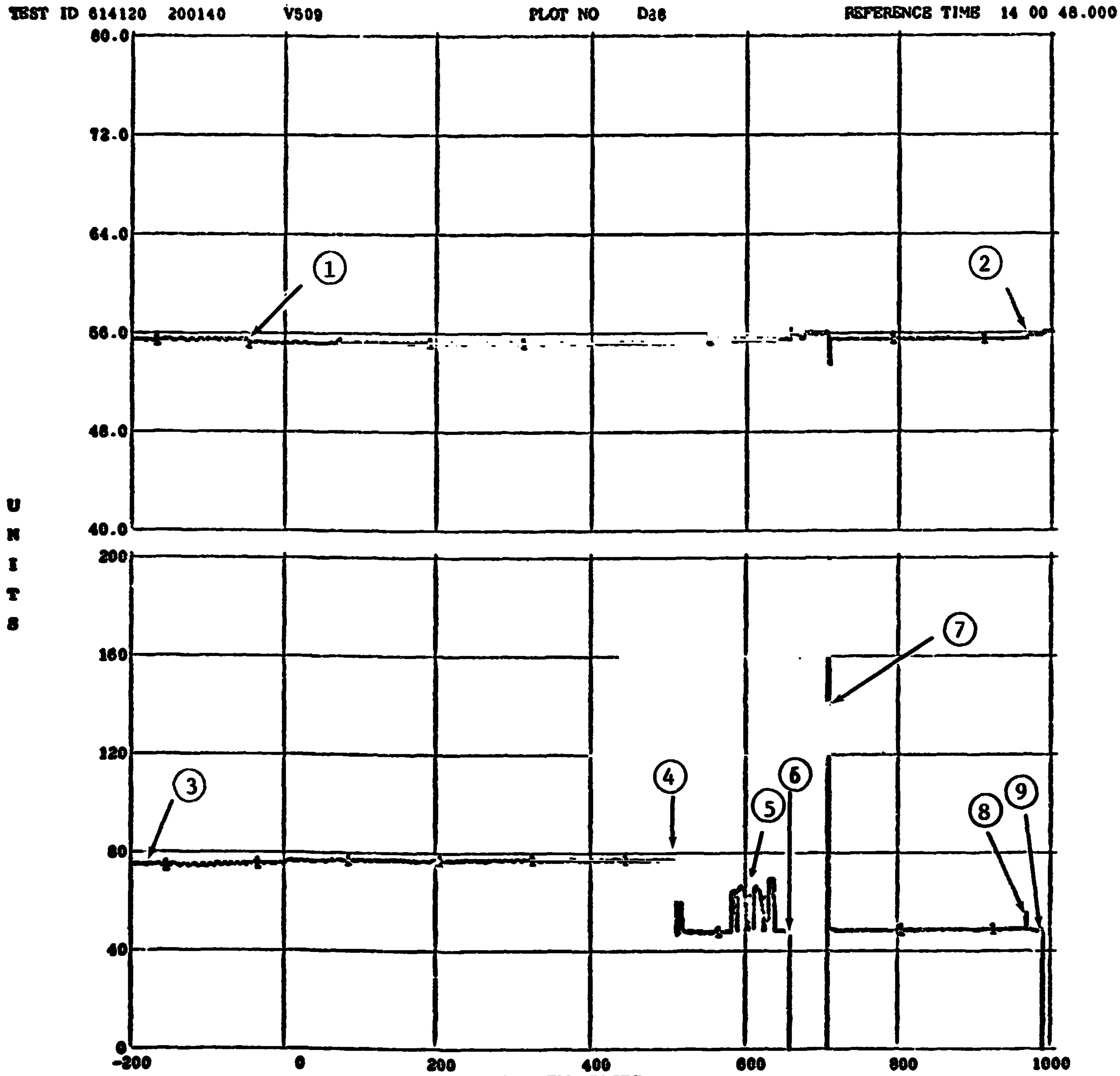
1 External/Internal Power Transfer
2 Internal/External Power Transfer
3 PU Activate
4 PU 4.5 Position
5 Engine Cutoff

Figure 13-2. Forward Bus No. 2 Profile -- Main Engine Firing



1 External/Internal Power Transfer
2 Internal/External Power Transfer
3 Engine Pump Purge "On"
4 Engine Start
5 APS Firings
6 LOX Press Cyclings
7 Second Burn "Off"
8 Engine Cutoff

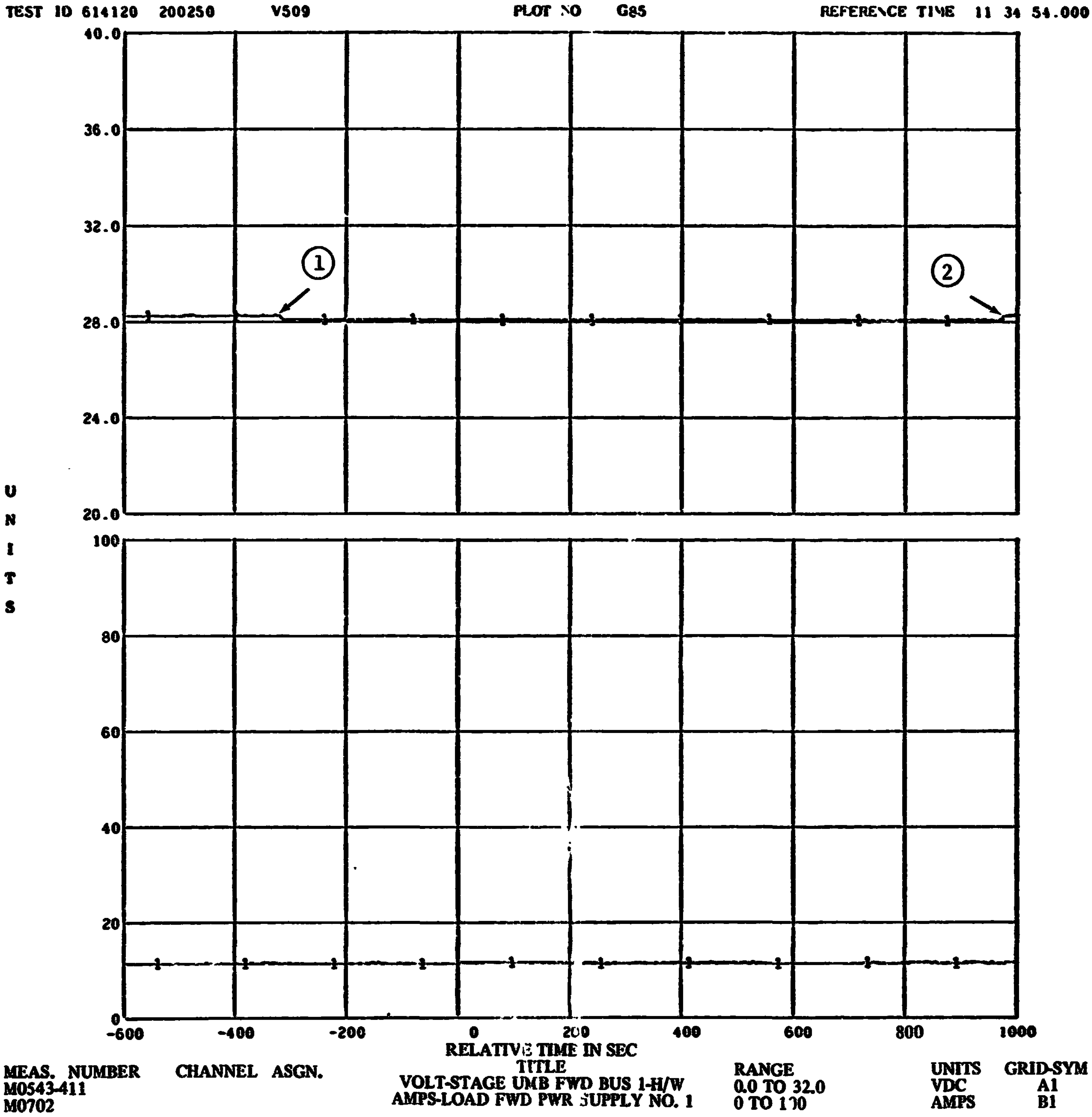
Figure 13-3. Aft Bus No. 1 Profile -- Main Engine Firing



MEAS. NUMBER	CHANNEL ASGN.	TITLE	RANGE	UNITS	GRID-SYM
M0540-404		VOLT-STAGE UMB AFT BUS 2-H/W	0.0 TO 64.0	VDC	A1
M0701		AMPS-LOAD AFT PWR SUPPLY NO. 2	0 TO 150	AMPS	B1

1 External/Internal Power Transfer
2 Internal/External Power Transfer
3 Aux and C/D Pumps Operating
4 Childown Pumps "Off"
5 Gimbal Program
6 Aux Pump "Off"
7 Aux Pump "On"
8 Engine Cutoff
9 Aux Pump "Off"

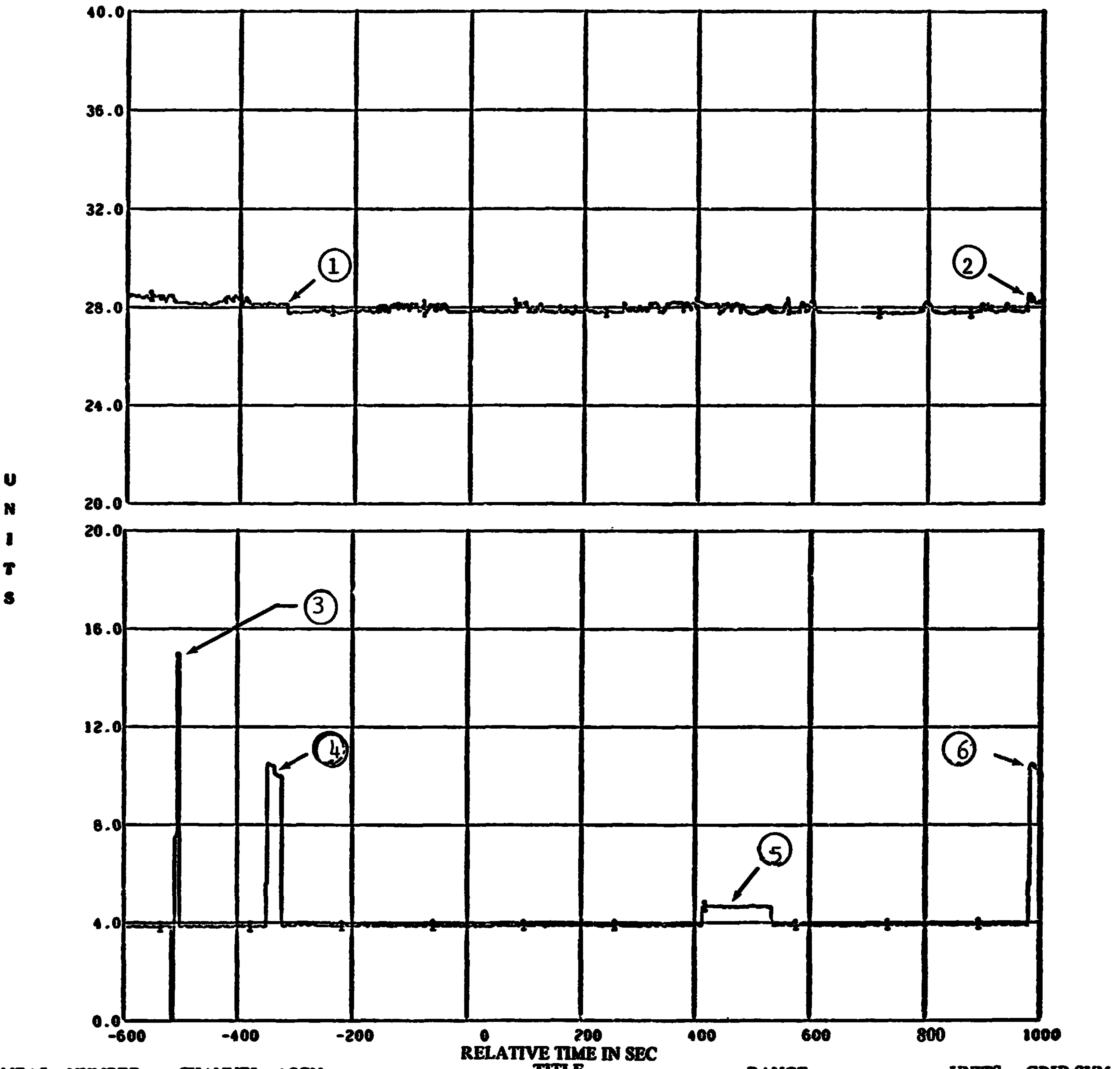
Figure 13-4. Aft Bus No. 2 Profile -- Main Engine Firing



1 External/Internal Power Transfer
2 Internal/External Power Transfer

Figure 13-5. Forward Bus No. 1 Profile -- Burner Firing

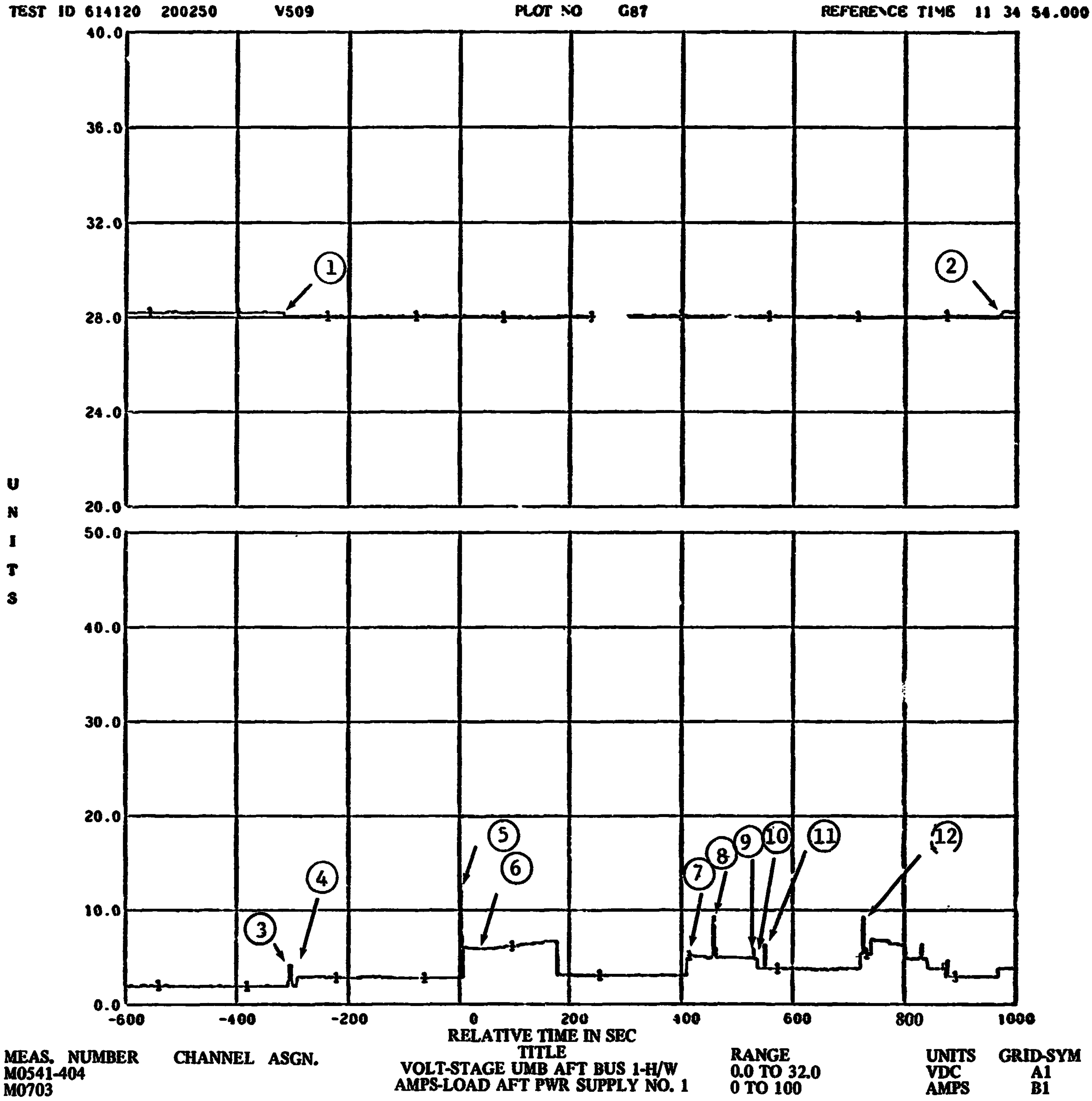
TEST ID 614120 200250 V509 PLOT NO G86 REFERENCE TIME 11 34 54.000



MEAS. NUMBER	CHANNEL ASGN.	TITLE	RANGE	UNITS	GRID-SYM
M0542-411		VOLT-STAGE UMB FWD BUS 2-H/W	0.0 TO 32.0	VDC	A1
M0700		AMPS-LOAD FWD PWR SUPPLY NO. 2	0 TO 15.0	AMPS	B1

1 External/Internal Power Transfer
2 Internal/External Power Transfer
3 Ground Instrumentation System Calibration
4 Prelaunch Checkout Group Energized
5 PU Mixture Ratio 4.5:1 Command
6 Prelaunch Checkout Group Energized

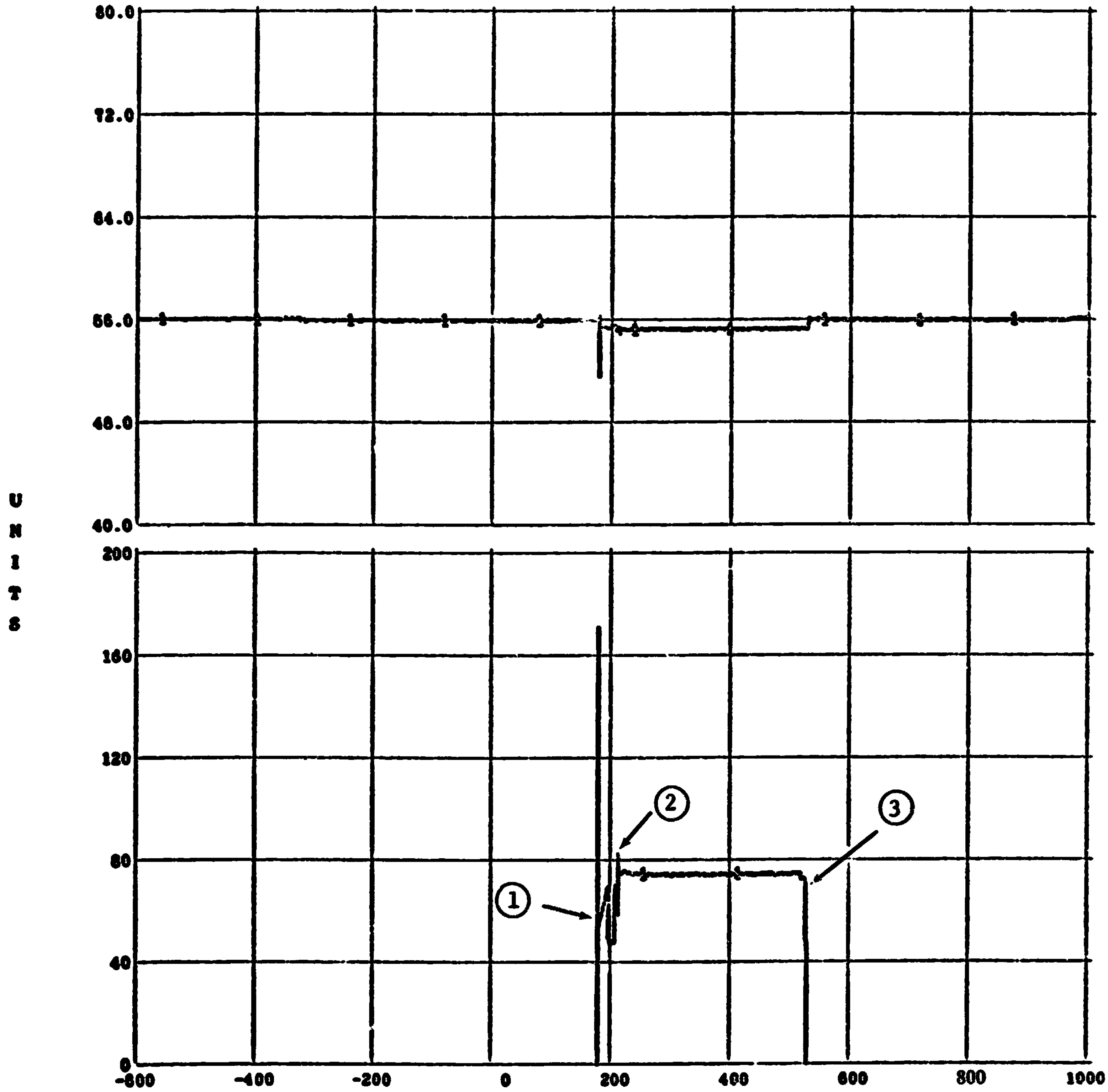
Figure 13-6. Forward Bus No. 2 Profile -- Burner Firing



1 External/Internal Power Transfer
2 Internal/External Power Transfer
3 Bnr Low Temp Sim Cycle
4 LOX NPV Vlv Open
5 Bnr Start
6 LOX Repress Sys Actuated
7 Second Brn Rly On
8 Bnr Shutdown
9 Ullage Engine Off
10 LH2 Step Press Vlv Deenergized
11 LH2 Cont Vent Vlvs Open
12 Ambient Repress Sequence

Figure 13-7. Aft Bus No. 1 Profile -- Burner Firing

TEST ID 614120 200250 V509 PLOT NO G88 REFERENCE TIME 11 34 54.000



MEAS. NUMBER	CHANNEL ASGN.	TITLE	RANGE	UNITS	GRID-SYM
M0540-404		VOLT-STAGE UMB AFT BUS 2-H/W	0.0 TO 64.0	VDC	A1
M0701		AMPS-LOAD AFT PWR SUPPLY NO. 2	0 TO 150	AMPS	B1

1 Aux Pump "On"
2 Chilldown Pumps "On"
3 Aux and Chilldown Pumps "Off"

Figure 13-8. Aft Bus No. 2 Profile -- Burner Firing

14. HYDRAULIC SYSTEM

14.1 Hydraulic System Operation

The hydraulic system test program was conducted during countdown number 614120, during which the engine was successfully positioned and gimbaled. System running time for this test, from auxiliary pump ON prior to simulated liftoff to auxiliary pump OFF following cutoff, was 1,465 sec. The gimbal program was initiated after the engine start side loads subsided and the support links dropped. The auxiliary pump was turned off for 50 sec following the gimbaling program to verify satisfactory engine-driven pump operation.

Significant event times are presented in the following table:

Event	Approximate Time (sec)
Auxiliary Pump ON	T_0 -477
(Simulated Liftoff)	(T_0 +0)
Engine Ignition (engine-driven pump start)	T_0 +511
Support Links Dropped	T_0 +557
Gimbal Program Start	T_0 +580
Gimbal Program Stop	T_0 +636
Auxiliary Pump OFF	T_0 +657
Auxiliary Pump ON	T_0 +706
Engine Cutoff	T_0 +966
Auxiliary Pump OFF	T_0 +988

14.2 System Pressure at Salient Times

The GN2 accumulator precharge pressure was 2,268 psia at 56 deg F just prior to starting the auxiliary hydraulic pump (T -477 sec). Correcting the gas pressure to 70 deg F temperature, the pressure value was within the 2,[illegible]0 ±50 psia allowable limits.

Test data indicated that the auxiliary pump discharge pressure increased to 3,635 psia in 17.5 sec after energizing the pump motor. Steady system pressure was maintained up to engine start. System pressure was 3,640 psia both before and after engine ignition, indicating no change in engine pump operation.

During the brief period of auxiliary pump cutoff (50 sec), the engine-driven pump pressure was 3,620 psia. This test indicated that the engine-driven pump was operating properly and within the required limits (3,500 to 3,665 psia).

The system leakage flow (0.76 gpm) was obviously supplied by the auxiliary pump during the burn prior to the gimbal program. This is evidenced by the fact that the auxiliary pump compensator setting was 20 psi higher than the main pump setting and by the auxiliary pump current draw of 48 amp during this time period. After the auxiliary pump was turned off at the conclusion of the test, system bleed-down time was 40 sec.

Hydraulic system and reservoir pressures are shown in figure 14-1. The following is a tabulation of the pressures during significant periods of interest:

Time (sec)	System Pressure (psia)(D549)	Reservoir Pressure (psia) (D550)
T_0 -458 (aux pump ON)	3,635	170
T_0 +0 (Simulated Liftoff)	3,640	170
T_0 +512 to 519 (Engine Start Trans)	3,670 max 3,580 min	173
T_0 +581 to 636 (Gimbal)	3,665 max 3,540 min	184 max 165 min
T_0 +980 (prior to aux pump OFF)	3,640	175

14.3 Reservoir Level at Salient Times

Reservoir level prior to system operation was 89 percent at an oil temperature of 43 deg F. The minimum level during operation was 33 percent, which occurred 175 sec after auxiliary pump start. Reservoir level history is shown in figure 14-2.

14.4 Hydraulic Fluid Temperature History

Pump inlet (C0699) and reservoir oil (C0051) temperatures are shown in figure 14-3.

14.5 Engine Side Loads

Peak loads in the support links during engine start transients were as follows:

Item	Load (lbf)
Pitch Link	+17,000 - 15,000
Yaw Link	+17,000 - 21,000

14.6 Hydraulic Fluid Flowrates

Approximations from reservoir fill and emptying rates are presented in the following table:

Item	Flow (gpm)	Allowable (gpm)
System Internal Leakage	0.76	0.4 to 0.8
Auxiliary Pump Max Flowrate	1.84	1.50 min

14.7 Auxiliary Pump Motor Voltage and Current

The aft battery No. 2 current load during the test is shown in figure 14-2. The following table shows the values observed during significant time periods:

Time (sec)	Aft Bus No. 2 Voltage Supply (m540) (51-61 vdc allowable)	Aft Battery No. 2 Current Load (M022) (85 amp max)
T_0 +0	55	76.5
T_0 +530 (after ignition C/D pumps OFF)	55.4	48
T_0 +581 to +637 (Gimbal)	56.5 max 55 min	70 max 48 min
T_0 +707 (Turn aux pump on after brief shutdown)	46 min	170 peak*
T_0 +950 (prior to engine C/O)	56.6	48.2

*Maximum allowable inrush current is 300 amp.

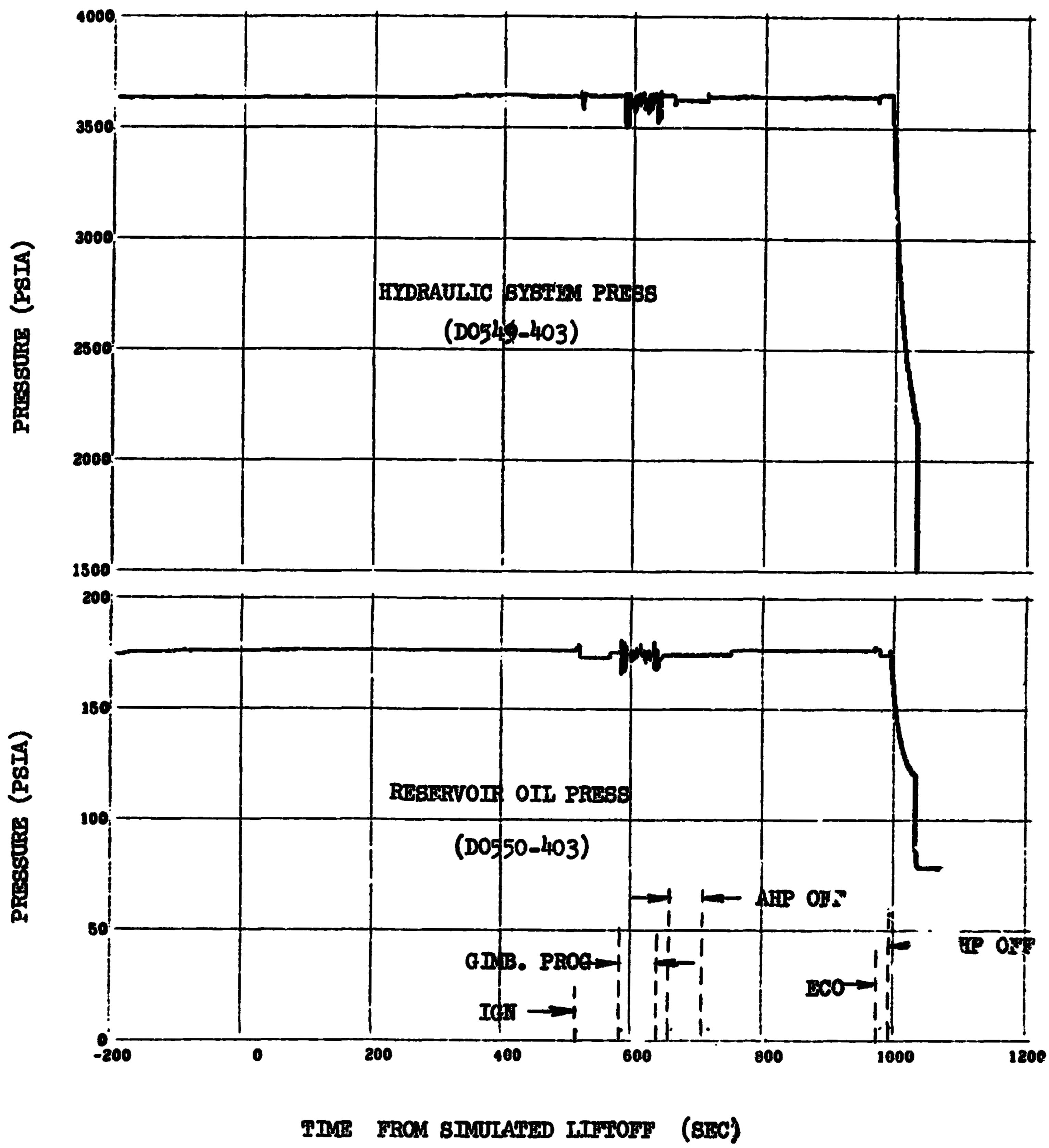
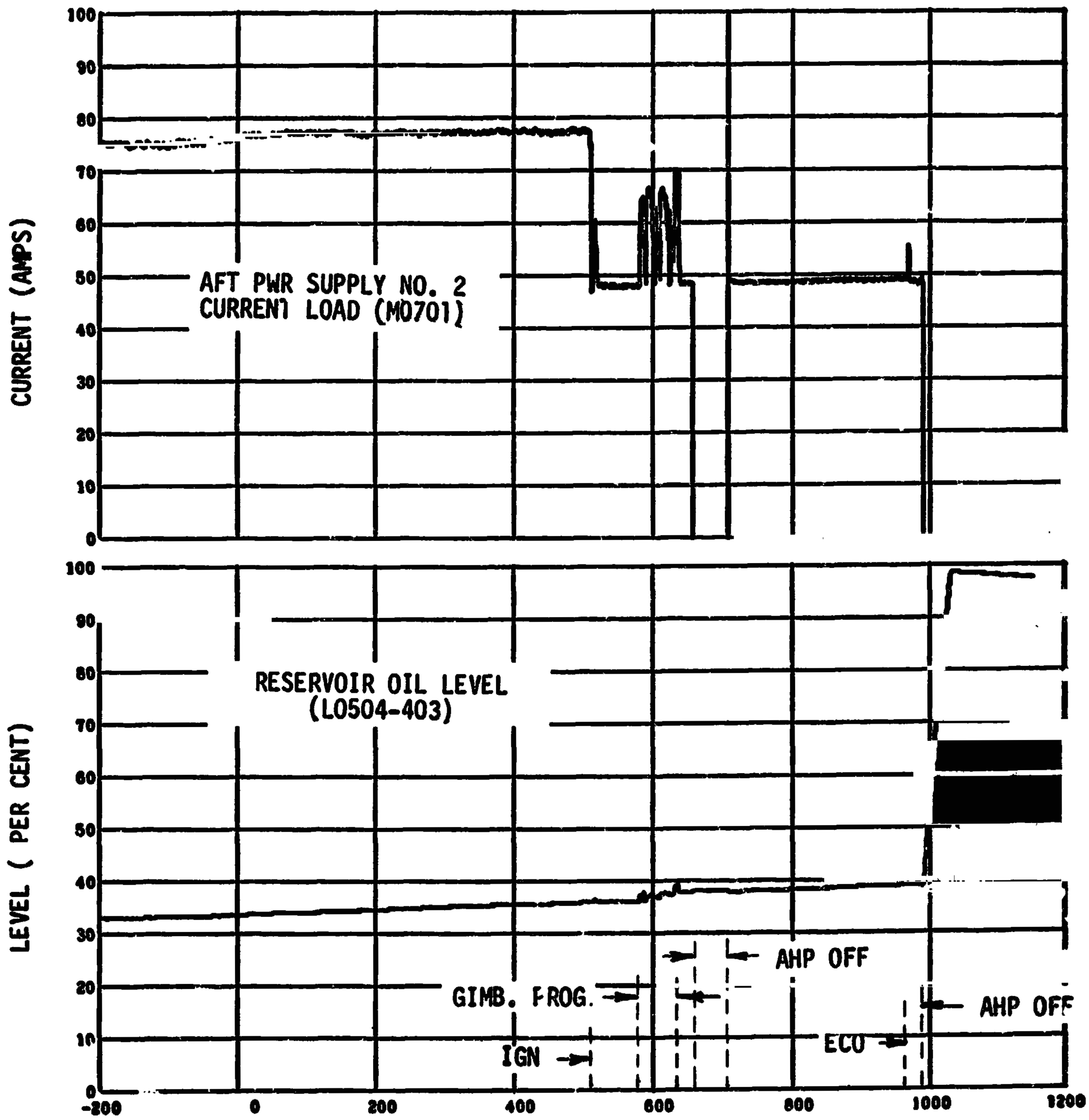


FIGURE 14-1 - HYDRAULIC SYSTEM PRESSURE



TIME FROM SIMULATED LIFTOFF (SEC)

FIGURE 14-2 - RESERVOIR LEVEL AND CURRENT LOAD

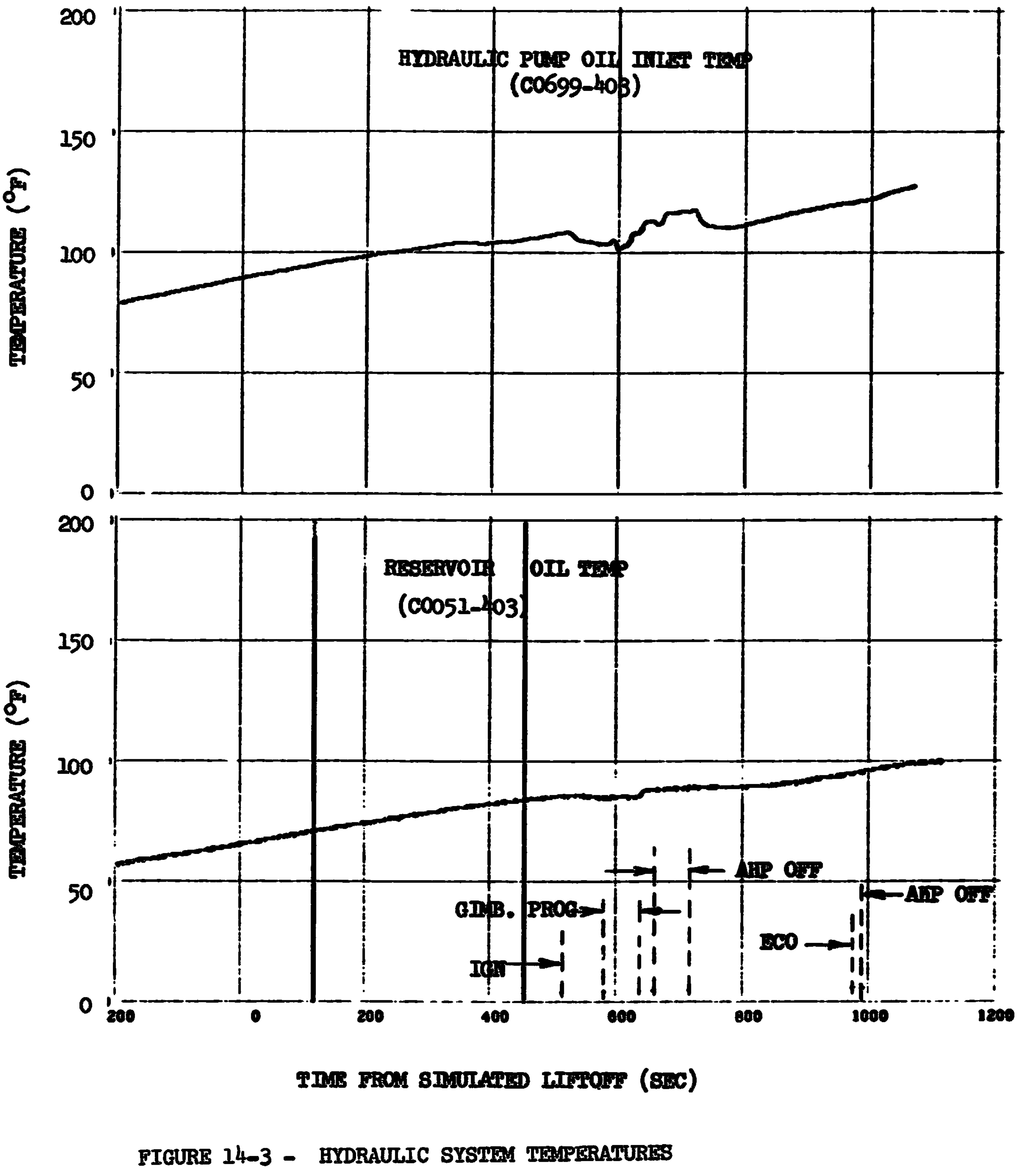


FIGURE 14-3 - HYDRAULIC SYSTEM TEMPERATURES

15. FLIGHT CONTROL SYSTEM

The dynamic response of the hydraulic servo thrust vector control system was measured while the J-2 engine was gimbaling during the acceptance firing. The performance of the pitch and yaw hydraulic servo control system was acceptable.

15.1 Actuator Dynamics

The frequency response test of the pitch and yaw hydraulic servo control system for $\pm$ 0.50 deg sinusoidal signal between 0.6 and 9 cps, and for a $\pm$ 0.25 deg sinusoidal signal between 0.6 and 2 cps verified the acceptability of the actuator responses. The acceptable limits and the gain and phase plots within these limits are presented in figures 15-1 and 15-2.

15.2 Engine Slew Rates

A nominal 2-deg step command was applied to the pitch and yaw actuators from which the engine slew rates were determined. The minimum acceptable engine slew rate is 8 deg/sec, which corresponds to an actuator piston travel rate of 1.66 ips. A nominal slew rate for a 2-deg step without the effects of gimbal friction is 13.6 deg/sec. The measured values were acceptable and are listed in the following table:

Actuator	Condition	Engine Travel Deg	Engine Slew Rate Deg/Sec
Pitch	Retract	0.0 to +2.0	11.3
	Extend	+2.0 to 0.0	11.9
	Extend	0.0 to -2.0	11.9
	Retract	-2.0 to 0.0	11.0
Yaw	Extend	0.0 to +2.0	11.8
	Retract	+2.0 to 0.0	11.4
	Retract	0.0 to -2.0	11.8
	Extend	-2.0 to 0.0	11.6

The minimum engine slew rate obtained is 11.0 deg/sec which corresponds to an actuator piston travel of 2.28 ips. In all cases, each actuator exceeded the minimum acceptable piston travel rate of 1.66 ips.

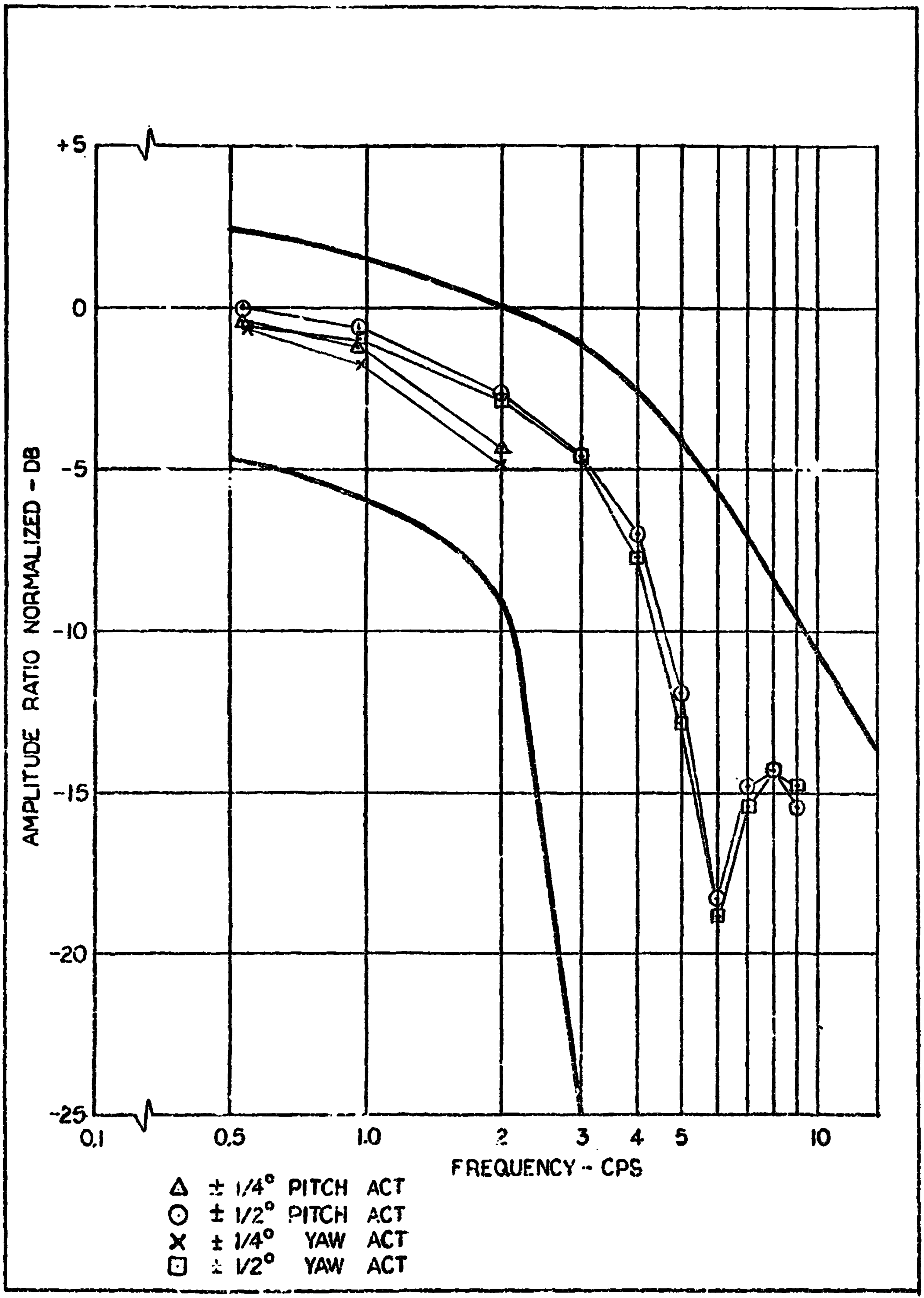


Figure 15-1 Actuator Response - Gain

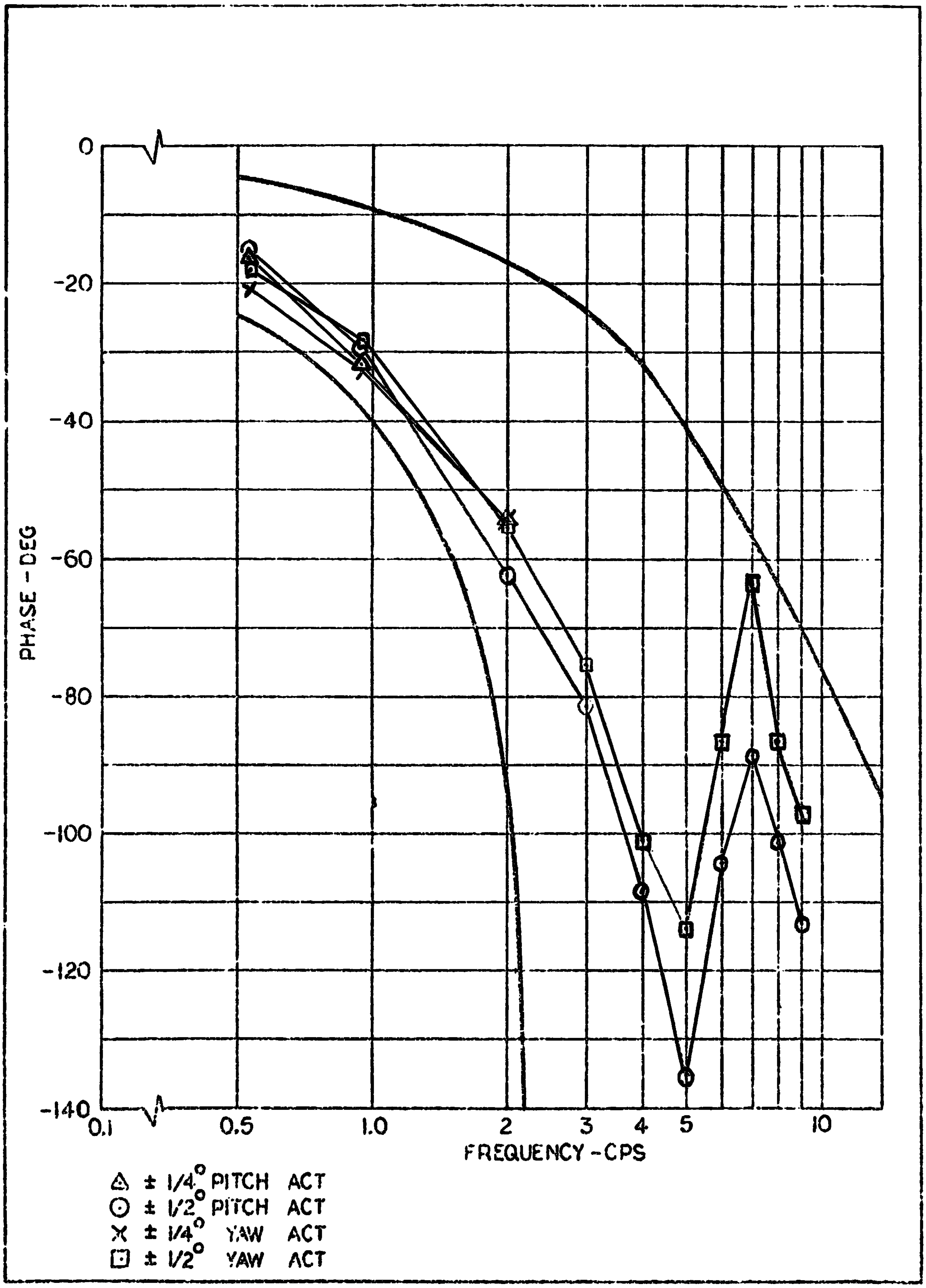


Figure 15.2 Actuator Response - Phase Lag

16. STRUCTURAL SYSTEMS

Structural integrity of the S-IVB-509 Stage was maintained for the vibration, temperature, pressure, and thrust load conditions of the Acceptance Firing Test. With the exception of debonding and cracking of Korotherm ablative coating at a local area on the Forward Skirt, no structural irregularities were encountered as a result of cryogenic loading, static firing, and O_2 - H_2 Burner firing. The damaged Korotherm coating is to be repaired under the direction of the MMRE Department. The Korotherm damage does not occur under CDDT or launch conditions at FTC due to the more effective thermal conditioning of the Forward Skirt at the launch facility.

16.1 Common Bulkhead

The results of the gas sample surveys, combined with satisfactory Common Bulkhead decay checks, indicate the bulkhead is sound and leak tight. During the actual acceptance firing, the bulkhead internal pressure readings were less than 1 psia. Gas sample analyses consistently indicated negligible quantities of hydrogen and helium gases within the Common Bulkhead. The pressure decay history and gas sample analyses recorded during prefire pumpdown, static firing, and post-firing activities are presented in Report DAC-61243, "S-IVB-509 Stage Acceptance Firing 15 Day Report Sacramento Test Center," dated June, 1969.

16.2 Exterior Structure

A post-firing visual inspection of the S-IVB-509 Stage exterior and accessible interior revealed no debonding of supports or brackets. The only evident structural degradation was debonding and cracking of Korotherm ablative coating around the Forward Skirt auxiliary tunnel area. The affected area extended from Stringer 13 through Stringer 18 and approximately 5 inches forward of the Forward Skirt tank joint. No cracking or peeling was noted in the main tunnel area.

16.3 LH_2 Low Pressure Ducts

A post-test inspection revealed frost on the entire length of the LH_2 Feed Line lower low pressure duct, indicating a loss of vacuum. A gas sample showed 97 percent GH_2 and 3 percent He gas. An investigation showed that the lower LH_2 Feed Line outlet bellows had cracked in the second convolute allowing the GH_2 and He to seep into the vacuum cavity. A failure analysis and subsequent test program showed that the bellows experienced a critical flow resonance condition at the lower propellant mixture ratios which caused a fatigue failure in the bellows. Corrective action has been initiated by ECP 3219 which will fabricate and install flow liners in the low pressure ducts to eliminate any flow resonance in the bellows. Effectivity of the change is 506N and subsequent stages.

17. THERMOCONDITIONING AND PURGE SYSTEMS

17.1 Aft Skirt Thermoconditioning and Purge System

The aft skirt environmental purge system thermally conditioned the aft skirt area with air and GN2. The air purge was initiated prior to LOX loading, and was switched to GN2 prior to LH2 loading. Following LH2 loading, the air purge was reinitiated for test stand inspection, and then was switched back to GN2 for the rest of static firing. The purge flowrate was maintained essentially constant at the nominal 3,600 scfm, and the aft skirt environmental temperature (C0663) was approximately constant at 551 deg R.

17.2 Forward Skirt Environmental Control and Thermoconditioning System

17.2.1 Forward Skirt Purge

The forward environmental purge system supplied the forward skirt with thermally conditioned GN2. The GN2 purge of the forward skirt was initiated prior to LOX loading and continued throughout the test until the completion of the tank purges. A flowrate of 283 scfm was maintained. The forward skirt GN2 supply temperature (C0768) was maintained between 502 and 524 deg R.

17.2.2 Forward Skirt Thermoconditioning System

The forward skirt thermoconditioning system was supplied with coolant throughout the acceptance firing by the Model DSV-4B-359 Servicer. The coolant supply temperature (C0753) was maintained between 520 and 527 deg R.

18. EFFECTIVENESS ENGINEERING

All functional failures of Flight Critical Items (FCI) and Ground Support Equipment/Special Attention Items were investigated by Effectiveness Engineering. Significant malfunctions of FCI's documented are noted in table 18-1.

TABLE 18-1 (Sheet 1 of 2)

FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N and S/N	PART NAME	TROUBLE DESCRIPTION	CAUSE	ACTION TAKEN
1A66241-511 S/N 458915	Pump, Hydraulic, Auxiliary Motor Driven	During post acceptance firing leak check, the auxiliary hydraulic pump leaked 288 drops/hour from check valve P/N 612706, S/N 47. The maximum allowable leakage is 200 drops/hour per SCD 1A66241-511.	Suspect defective check valve P/N 612706, S/N 47.	Due to the deteriorating and marginal operation of this component, the condition of this part has been deemed unacceptable for use. Per SEO 1A39300-A45-1, vendor to remove check valve P/N 612706, S/N 47 from pump S/N 458915 and install check valve P/N 612706, S/N 8 (obtain from pump S/N 454594). The reworked stage assembly to be checked per procedure 1B41006, Revision 5. The removed check valve S/N 47 and pump S/N 454594 to be returned to vendor for further evaluation.
1B67598-503 S/N 180	Valve, Check Pneumatic	During post acceptance firing leak checks, the check valve was found to have a reverse leakage of 65 scim with 1,450 psig. Prefiring leakage was 0 scim with 1,450 psig. SCD allows 50 sccm (3.1 scim).	To be determined.	This valve will be sent to Location A3-MRCC for further investigation and final disposition.

TABLE 18-1 (Sheet 2 of 2)

FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N and S/N	PART NAME	TROUBLE DESCRIPTION	CAUSE	ACTION TAKEN
103826 S/N J-2124	J-2 Engine	Pneumatic Control Package P/N 558130, S/N 4092997 had excessive leakage from the main regulator exhaust valve.	Leakage was caused by the actuator piston seal in the main fuel valve. This leakage exceeded the allowable for the main fuel valve piston seal. The leakage was via the pneumatic return system and was vented out the main regulator exhaust valve in the pneumatic control package.	Acceptable for use during acceptance firing of the stage. R/NAR has written an ROD stating that the leakage exceeded the allowable, but was acceptable. J-2 engine is a GFP item.
103826 S/N J-2124	J-2 Engine	1. Schrader valve P/N 558272-31 on G2 spark igniter cable leaked during post firing leak test per procedure 1B71877. 2. Schrader valve P/N 558272-31 on primary instrumentation package leaked during the same post firing leak test.	To be determined on UCR No. R005393 by R/NAR.	The Schrader valves were replaced and the new ones leak tested satisfactorily. UCR No. R005393 written by R/NAR. J-2 Engine is a GFP item.

TABLE AP 1-1 (Sheet 1 of 3)
ABBREVIATIONS

Item	Term
ac	Alternating current
Act	Actuator
APS	Auxiliary Propulsion System
ASI	Augmented Spark Igniter
attch	Attach
A_t	Throat area
Aux	Auxiliary
Btu	British thermal unit
Bgr	Bridge gain ratio
c_f	Thrust Coefficient
CDDT	Countdown Demonstration Test
Cfm	Cubic feet per minute
Contr	Control
cpg	Cycles per gallon
cps	Cycles per second
db	Decibel
dc	Direct current
DDAS	Digital Data Acquisition System
deg	Degree
DER	Digital Events Recorder
Disch	Discharge
DNA	Data not available
D/O	Dropout
DPF	Differential Pressure Feedback
EBW	Exploding bridgewire
ECC	Engine Cutoff Command
ECO	Engine Cutoff
EDS	Emergency Detection System
E/I	External/Internal
EMI	Electromagnetic Interference
EMR	Engine Mixture Ratio
ESC	Engine Start Command
F	Fahrenheit
F	Thrust
FCI	Flight Critical Items
Flt	Flight
ft	Feet
FM	Frequency modulation
FTC	Florida Test Center
Fwd	Forward
GG	Gas generator
GH2	Gaseous hydrogen
GIS	Ground Instrumentation System
GN2	Gaseous nitrogen
gpm	Gallons per minute
GSE	Ground support equipment
HB	Huntington Beach
He	Helium
Hg	Mercury
H_2O	Water
hr	Hour
hp	Horsepower
Hyd	Hydraulic
Hz	Hertz
in.	Inch
ips	Inches per second
IP&CL	Instrumentation Program and Components List
I_{sp}	Specific impulse

TABLE AP 1-1 (Sheet 2 of 3)
ABBREVIATIONS

Item	Term
IU	Instrument Unit
K	Kilo - 1,000 or 10^3
Kc	Kilocycle
KSC	Kennedy Space Center
lbf	Pounds force
lbm	Pounds mass
LH2	Liquid hydrogen
Loc	Location
LOX	Liquid oxygen
M&A	Manufacturing and Assembly
MDAC-WD	McDonnell Douglas Astronautics Company - Western Division
MR	Mixture ratio
ms	Millisecond
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
N/A	Not applicable
NPSP	Net positive suction pressure
P_c	Chamber pressure
PCM	Pulse code modulation
PDT	Pacific Daylight Time
pf	Picofarad
Posit	Position
pps	Pulses per second
Press	Pressure
psi	Pounds per square inch
psia	Pounds per square inch, absolute
psid	Pounds per square inch, differential
psig	Pounds per square inch, gauge
PST	Pacific Standard Time
Pt	Point
P/U	Pickup
PU	Propellant Utilization
Pwr	Power
R	Rankine
RACS	Remote Analog Checkout System
RAD	Radial
Refl	Reflected
Reg	Regulator
RF	Radio Frequency
RMR	Reference Mixture Ratio
rpm	Revolutions per minute
RSS	Root sum square
SAI	Special Attention Items
scc	Standard cubic centimeter
sci	Standard cubic inch
scim	Standard cubic inch per minute
scfm	Standard cubic foot per minute
sec	Second
sps	Samples per second
SSB	Single sideband
STC	Sacramento Test Center
sw	Switch
Syst	System
T_0	Simulated liftoff
TAN	Tangential

TABLE AP 1-1 (Sheet 3 of 3)
ABBREVIATIONS

Item	Term	Item	Term
Temp	Temperature		
T/M	Telemetry		
TP&E	Test Planning and Evaluation		
vac	Volts alternating current (100 vac)		
V	Volts		
VCL	Vehicle Checkout Laboratory		
vdc	Volts direct current		
Vib	Vibration		
vswr	Voltage standing wave ratio		
$\dot{W}_T$	Total mass flowrate		